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(54) **FREQUENCY SHIFTING A COMMUNICATIONS SIGNAL(S) IN A MULTI-FREQUENCY DISTRIBUTED ANTENNA SYSTEM (DAS) TO AVOID OR REDUCE FREQUENCY INTERFERENCE**

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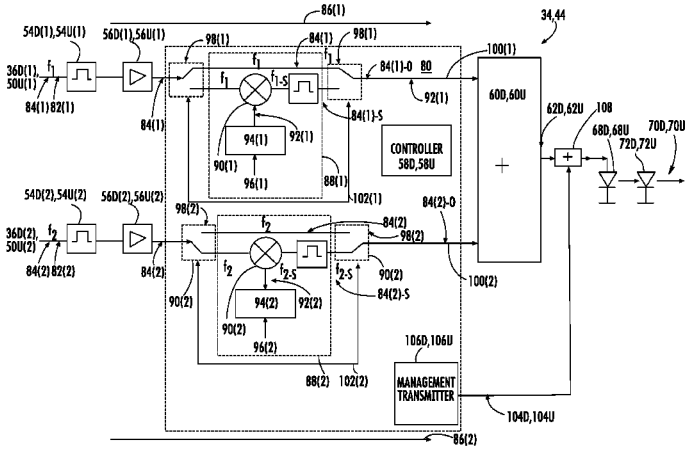
(57) **ABSTRACT**

Frequency shifting a communications signal(s) in a multiple frequency (multi-frequency) distributed antenna system (DAS) to avoid or reduce frequency interference is disclosed. Related devices, methods, and DASs are disclosed. Non-limiting examples of frequency interference include frequency band interference and frequency channel interference. As a non-limiting example, frequency interference in a multi-frequency DAS may result from non-linearity of a signal processing component generating an out-of-band harmonic of a first, in-use communications signal in a first frequency band, within different frequency band(s) of other in-use communications signal(s). To avoid or reduce such interference, embodiments disclosed herein involve predicting frequency interference that may result from processing received, in-use communications signals in multiple frequency bands to be distributed in a multi-frequency DAS. Frequency shifting is performed to avoid or reduce any interfering signal products produced from the signal processing of any in-use communications signals, from interfering in the frequencies of other in-use communications signals.

28 Claims, 10 Drawing Sheets



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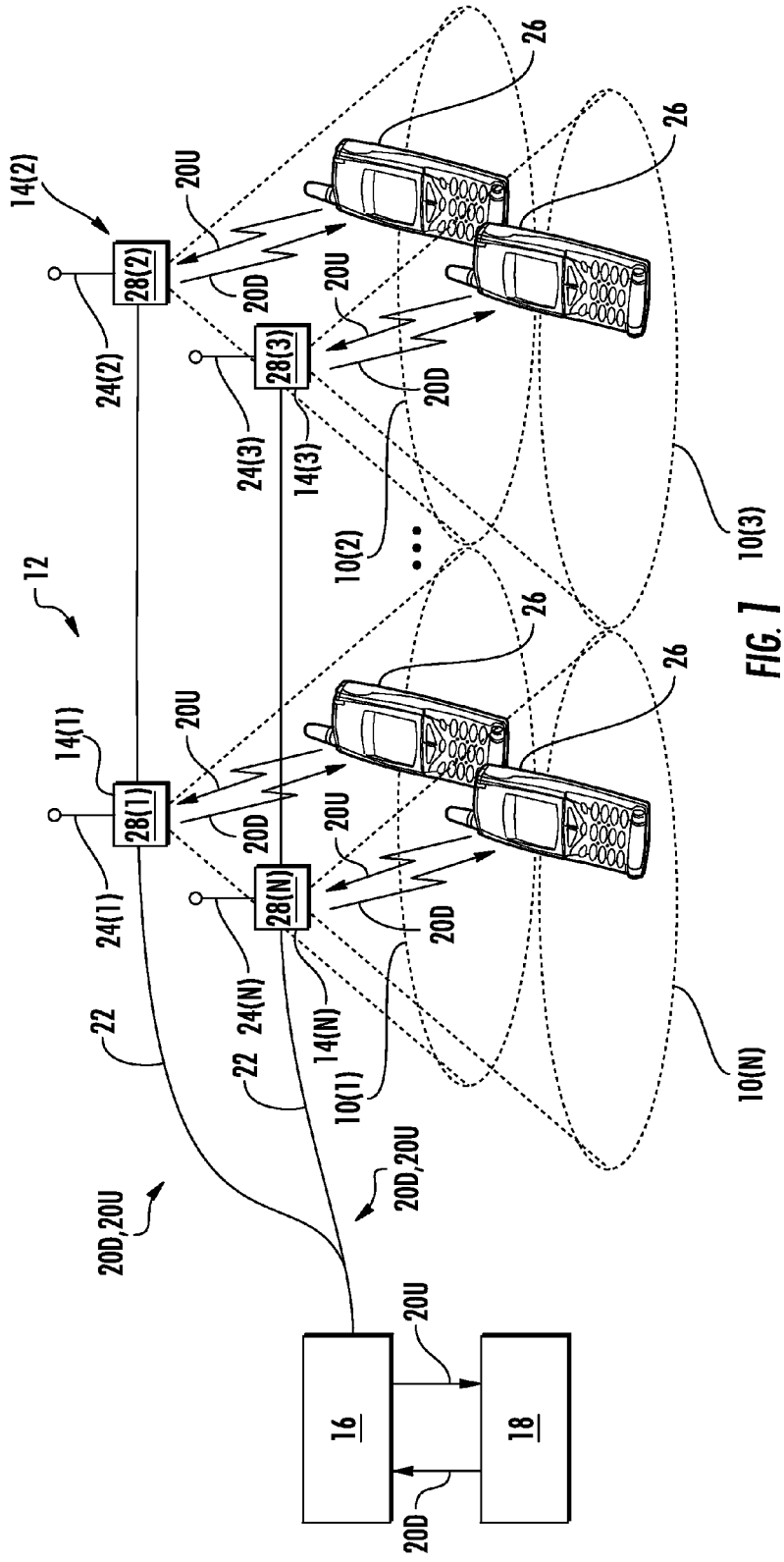
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14(1)
14(2)
14(3)
14(N)
16
18
20D
20U
20D,20U
22
24(1)
24(2)
24(3)
24(N)
26
28(1)
28(2)
28(3)
28(N)
10(1)
10(2)
10(3)
10(N)

FIG. 1

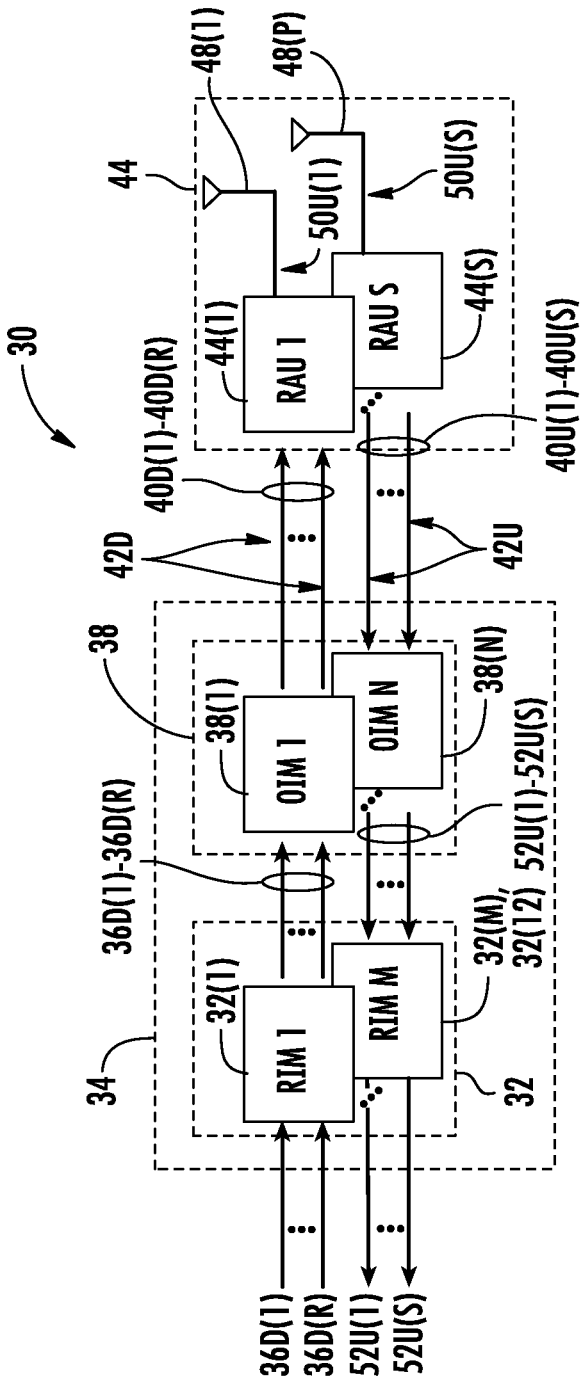

30
34
38
38(1)
38(N)
OIM 1
OIM N
32
32(1)
32(M), 32(12)
RIM 1
RIM M
44
44(1)
44(S)
RAU 1
RAU S
48(1)
48(P)
50U(1)
50U(S)
40D(1)-40D(R)
40U(1)-40U(S)
42D
42U
36D(1)-36D(R)
52U(1)-52U(S)
36D(1)
36D(R)
52U(1)
52U(S)

FIG. 2

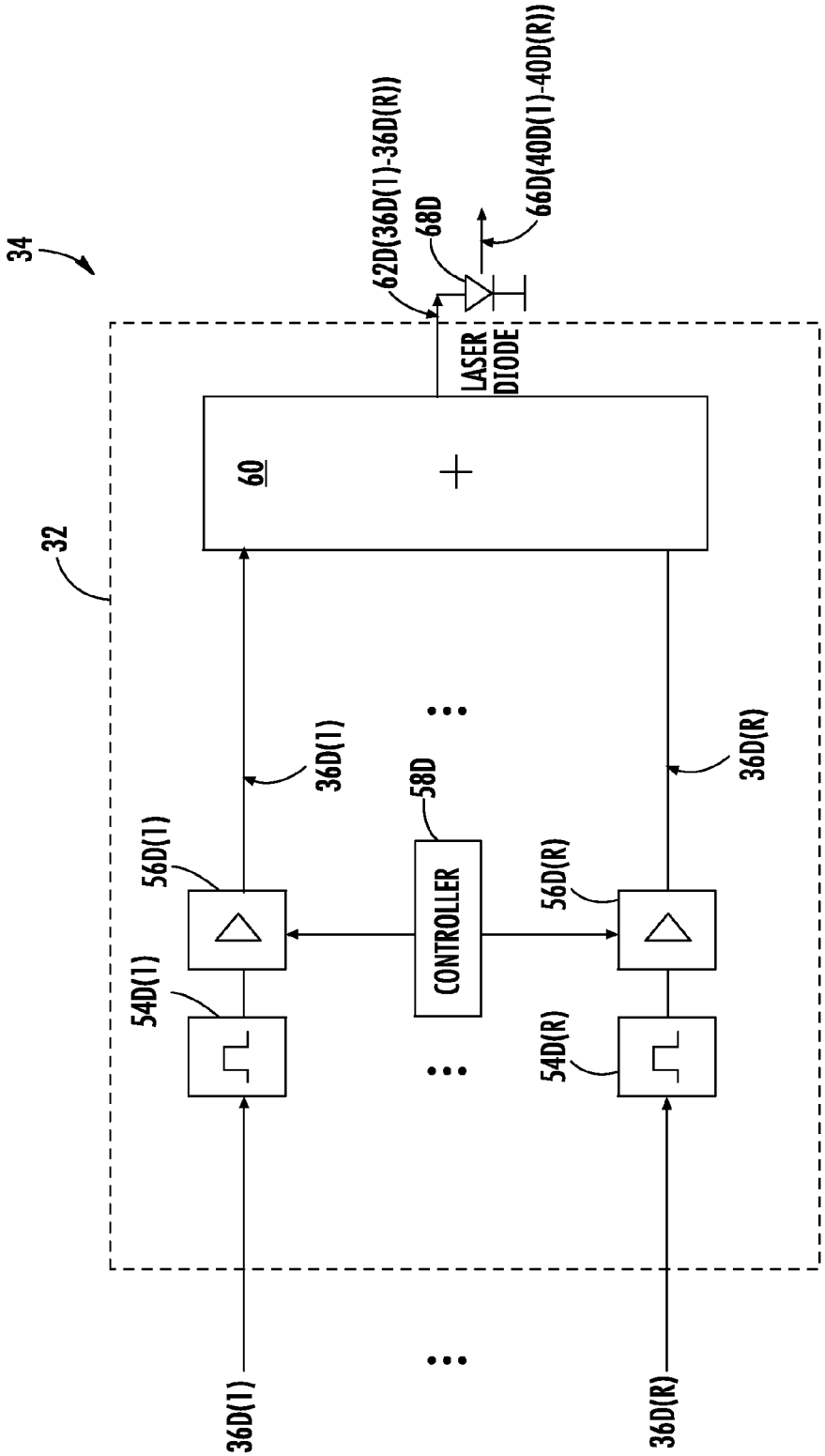

34
32
62D(36D(1)-36D(R))
68D
66D(40D(1)-40D(R))
LASER DIODE
60
36D(1)
36D(R)
58D
CONTROLLER
56D(1)
56D(R)
54D(1)
54D(R)
36D(1)
36D(R)

FIG. 3

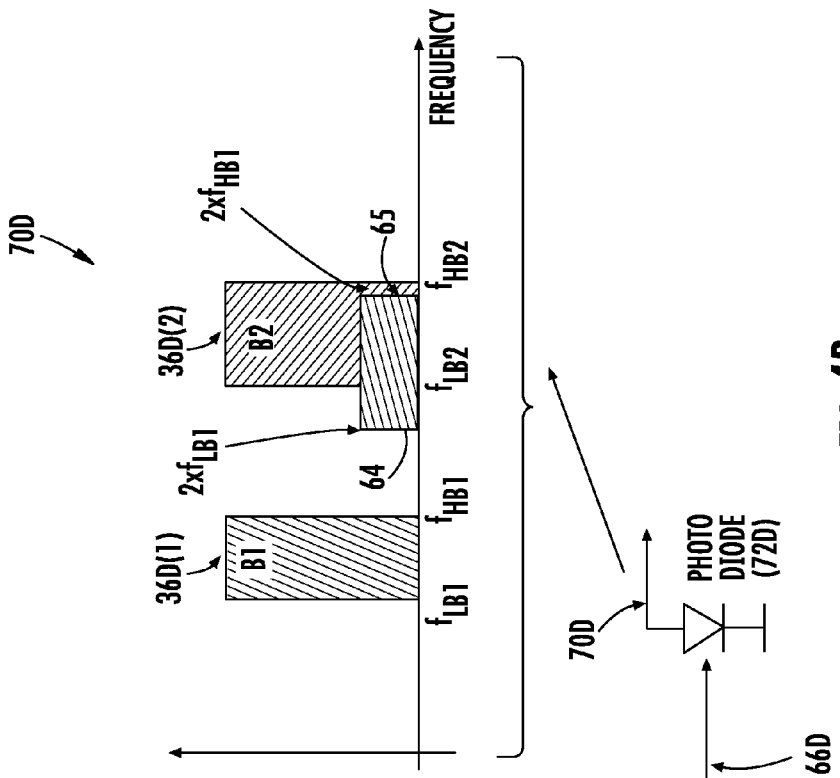

70D
FREQUENCY
$2xf_{HB1}$
65
f_{HB2}
36D(2)
B2
f_{LB2}
$2xf_{LB1}$
64
f_{HB1}
36D(1)
B1
f_{LB1}
70D
PHOTO DIODE (72D)
66D
62D
LASER DIODE (68D)

FIG. 4B

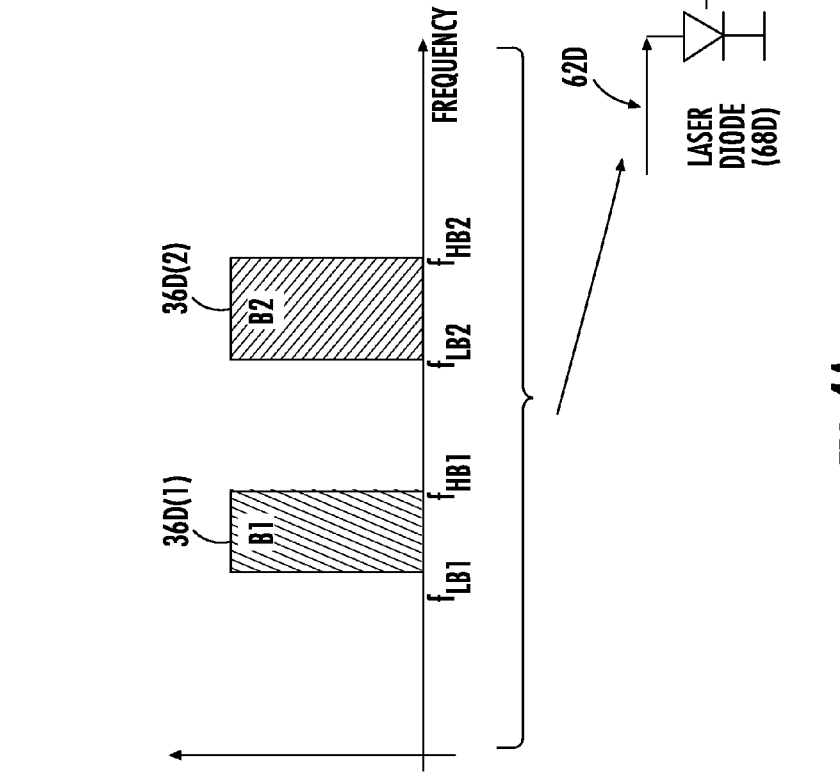

FREQUENCY
f_{HB2}
36D(2)
B2
f_{LB2}
f_{HB1}
36D(1)
B1
f_{LB1}
62D
LASER DIODE (68D)

FIG. 4A

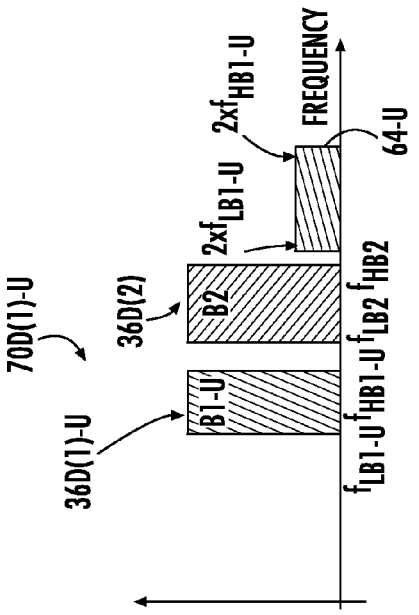


FIG. 5B

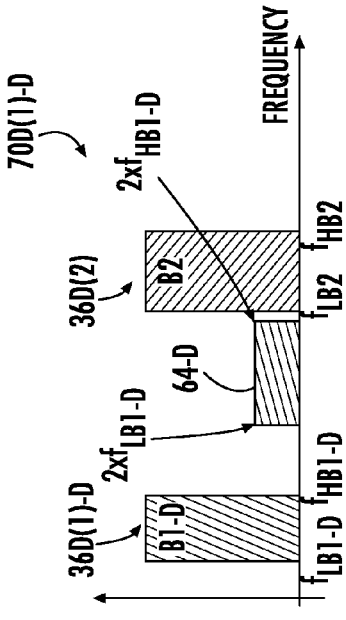


FIG. 5A

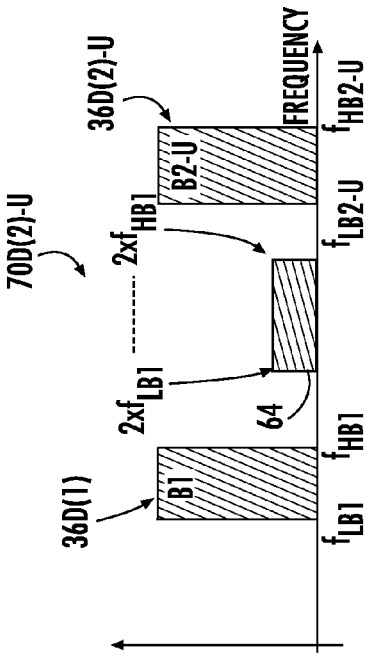


FIG. 5D

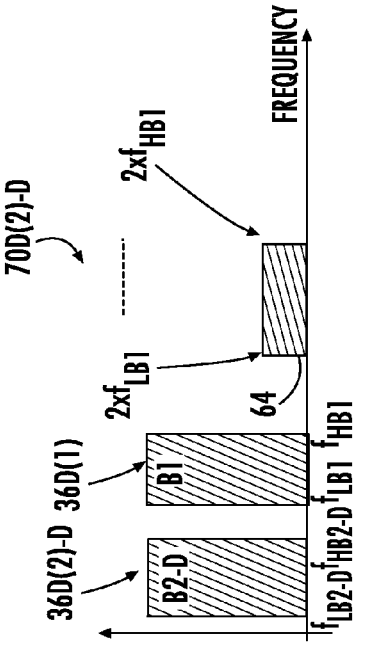
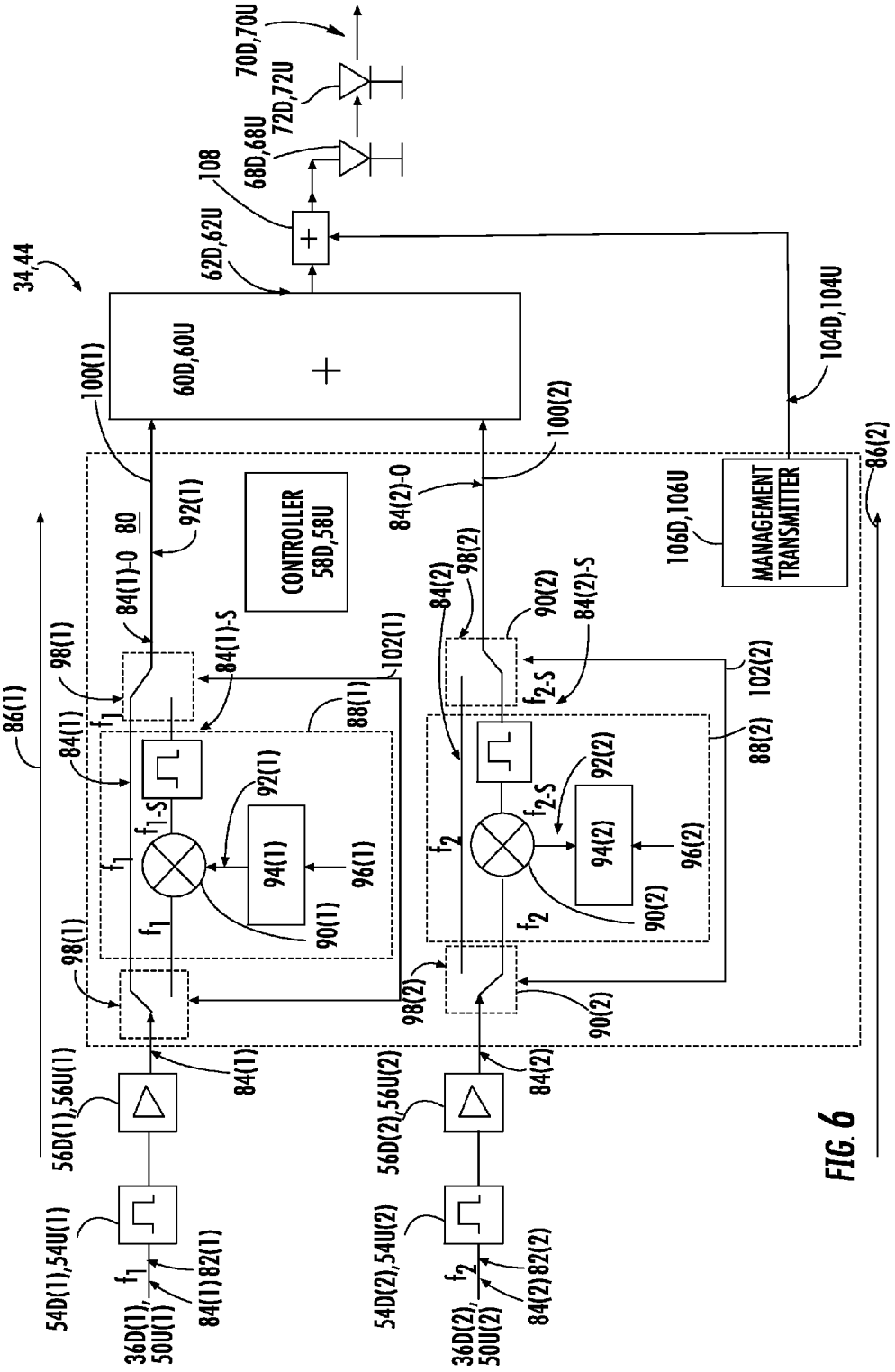


FIG. 5C


34,44
60D,60U
62D,62U
108
68D,68U
72D,72U
70D,70U
100(1)
100(2)
104D,104U
106D,106U
MANAGEMENT TRANSMITTER
CONTROLLER 58D,58U
80
86(1)
86(2)
92(1)
84(1)-O
84(2)-O
98(1)
98(2)
84(1)-S
84(2)-S
102(1)
102(2)
88(1)
88(2)
84(1)
84(2)
90(1)
90(2)
94(1)
94(2)
96(1)
96(2)
f_1
f_2
f_{1-S}
f_{2-S}
56D(1),56U(1)
56D(2),56U(2)
54D(1),54U(1)
54D(2),54U(2)
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36D(2), 50U(2)
82(1)
82(2)

FIG. 6

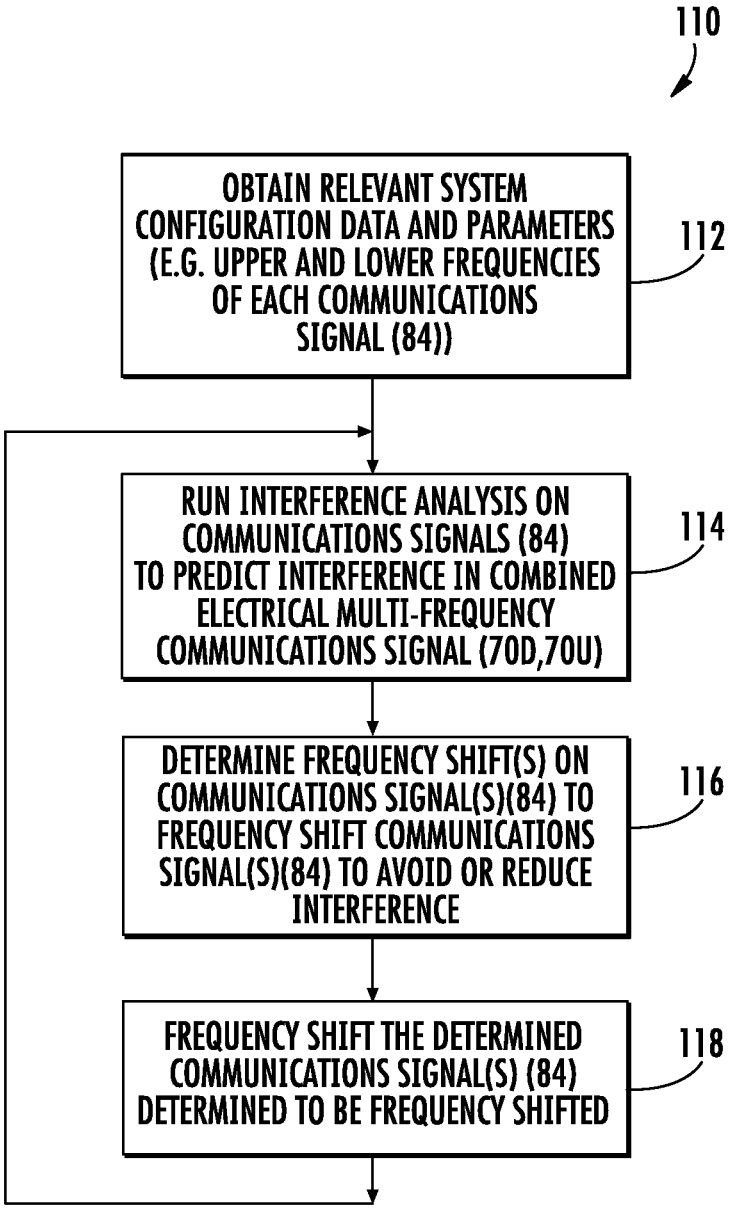

110
OBTAIN RELEVANT SYSTEM CONFIGURATION DATA AND PARAMETERS (E.G. UPPER AND LOWER FREQUENCIES OF EACH COMMUNICATIONS SIGNAL (84))
112
RUN INTERFERENCE ANALYSIS ON COMMUNICATIONS SIGNALS (84) TO PREDICT INTERFERENCE IN COMBINED ELECTRICAL MULTI-FREQUENCY COMMUNICATIONS SIGNAL (70D,70U)
114
DETERMINE FREQUENCY SHIFT(S) ON COMMUNICATIONS SIGNAL(S)(84) TO FREQUENCY SHIFT COMMUNICATIONS SIGNAL(S)(84) TO AVOID OR REDUCE INTERFERENCE
116
FREQUENCY SHIFT THE DETERMINED COMMUNICATIONS SIGNAL(S) (84) DETERMINED TO BE FREQUENCY SHIFTED
118

FIG. 7

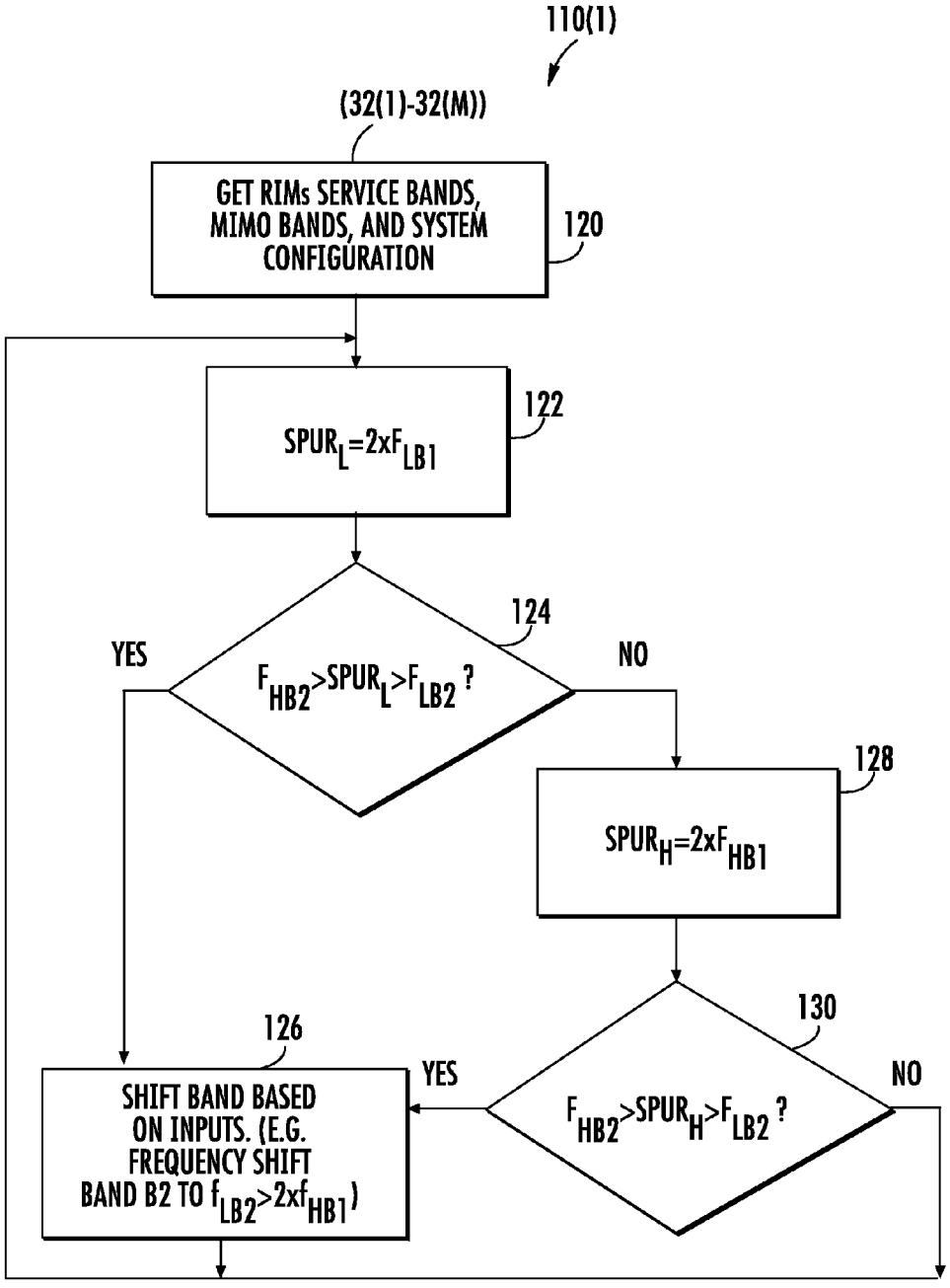
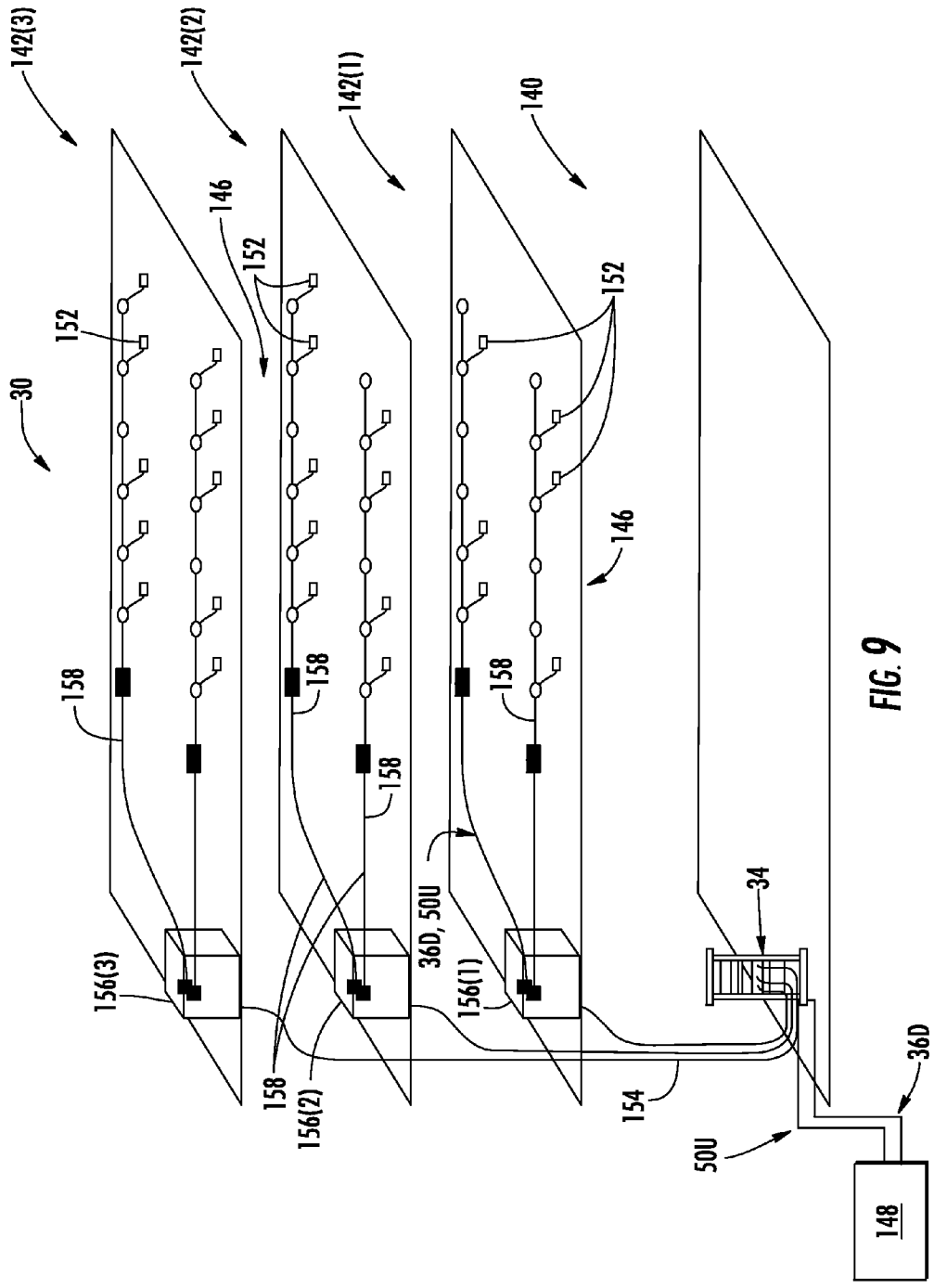

110(1)
(32(1)-32(M))
GET RIMs SERVICE BANDS, MIMO BANDS, AND SYSTEM CONFIGURATION
120
SPUR$_L$=2xF$_{LB1}$
122
124
YES
F$_{HB2}$>SPUR$_L$>F$_{LB2}$?
NO
128
SPUR$_H$=2xF$_{HB1}$
130
126
YES
SHIFT BAND BASED ON INPUTS. (E.G. FREQUENCY SHIFT BAND B2 TO f$_{LB2}$>2xf$_{HB1}$)
F$_{HB2}$>SPUR$_H$>F$_{LB2}$?
NO

FIG. 8


142(3)
142(2)
142(1)
140
146
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158
156(3)
156(2)
156(1)
36D, 50U
34
154
50U
36D
148

FIG. 9

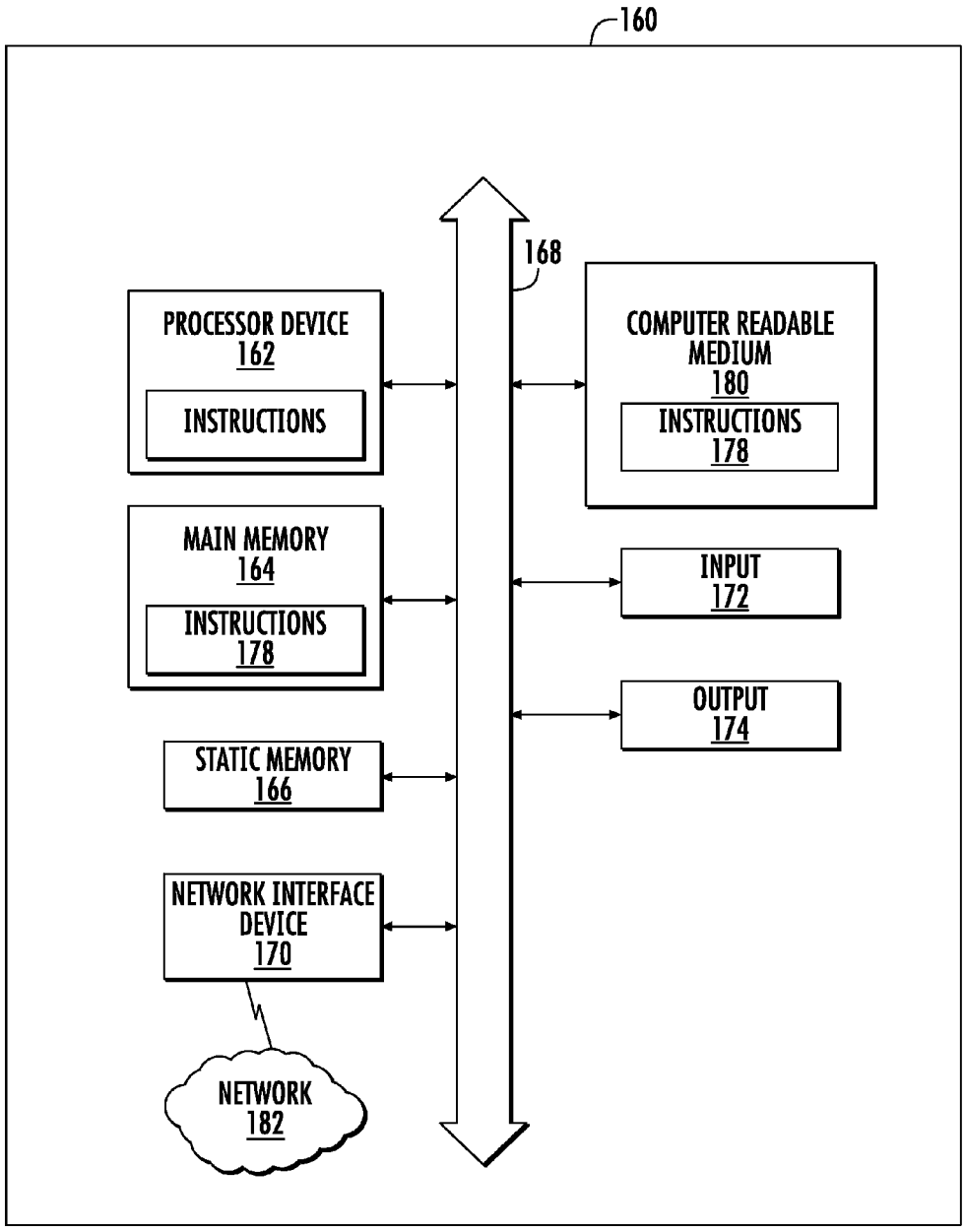
160
168
PROCESSOR DEVICE
162
INSTRUCTIONS
MAIN MEMORY
164
INSTRUCTIONS
178
STATIC MEMORY
166
NETWORK INTERFACE
DEVICE
170
NETWORK
182
COMPUTER READABLE
MEDIUM
180
INSTRUCTIONS
178
INPUT
172
OUTPUT
174

FIG. 10

FREQUENCY SHIFTING A COMMUNICATIONS SIGNAL(S) IN A MULTI-FREQUENCY DISTRIBUTED ANTENNA SYSTEM (DAS) TO AVOID OR REDUCE FREQUENCY INTERFERENCE

BACKGROUND

The technology of the present disclosure relates generally to distributed antenna systems (DASs), and more particularly to frequency shifting a communications signal(s) in a multiple frequency (multi-frequency) DAS to avoid or reduce potential frequency band interference, such as due to out-of-band harmonics generated by non-linearities in signal processing components.

Wireless communication is rapidly growing, with ever-increasing demands for high-speed mobile data communication. As an example, local area wireless services (e.g., so-called "wireless fidelity" or "WiFi" systems) and wide area wireless services are being deployed in many different types of areas (e.g., coffee shops, airports, libraries, etc.). Distributed communications or antenna systems communicate with wireless devices called "clients," "client devices," or "wireless client devices," which must reside within the wireless range or "cell coverage area" in order to communicate with an access point device. Distributed antenna systems are particularly useful to be deployed inside buildings or other indoor environments where client devices may not otherwise be able to effectively receive radio-frequency (RF) signals from a source, such as a base station for example. Example applications where distributed antenna systems can be used to provide or enhance coverage for wireless services include public safety, cellular telephony, wireless local access networks (LANs), location tracking, and medical telemetry inside buildings and over campuses.

One approach to deploying a distributed antenna system involves the use of RF antenna coverage areas, also referred to as "antenna coverage areas." Antenna coverage areas can be formed by remotely distributed antenna units, also referred to as remote units (RUs). The remote units each contain or are configured to couple to one or more antennas configured to support the desired frequency(ies) or polarization to provide the antenna coverage areas. Antenna coverage areas can have a radius in the range from a few meters up to twenty meters as an example. Combining a number of remote units creates an array of antenna coverage areas. Because the antenna coverage areas each cover small areas, there typically may be only a few users (clients) per antenna coverage area. This arrangement generates a uniform high quality signal enabling high throughput supporting the required capacity for the wireless system users.

As an example, FIG. **1** illustrates distribution of communications services to coverage areas **10**(**1**)-**10**(N) of a DAS **12**, wherein 'N' is the number of coverage areas. These communications services can include cellular services, wireless services such as RFID tracking, Wireless Fidelity (WiFi), local area network (LAN), WLAN, and combinations thereof, as examples. The coverage areas **10**(**1**)-**10**(N) may be remotely located. In this regard, the remote coverage areas **10**(**1**)-**10**(N) are created by and centered on remote antenna units **14**(**1**)-**14**(N) connected to a central unit **16** (e.g., a head-end controller or head-end unit). The central unit **16** may be communicatively coupled to a base station **18**. If the DAS **12** is a broadband DAS, the central unit **16** receives downlink communications signals **20**D in multiple frequency bands for different communications services from the base station **18** to be distributed to the remote antenna units **14**(**1**)-**14**(N). The

remote antenna units **14**(**1**)-**14**(N) are configured to receive downlink communications signals **20**D from the central unit **16** over a communications medium **22** to be distributed as downlink communications signals **20**D to the respective coverage areas **10**(**1**)-**10**(N) of the remote antenna units **14**(**1**)-**14**(N). Each remote antenna unit **14**(**1**)-**14**(N) may include an RF transmitter/receiver (not shown) and a respective antenna **24**(**1**)-**24**(N) operably connected to the RF transmitter/receiver to wirelessly distribute the communications services to client devices **26** within their respective coverage areas **10**(**1**)-**10**(N).

With continuing reference to FIG. **1**, the remote antenna units **14**(**1**)-**14**(N) in the DAS **12** are also configured to receive uplink communications signals **20**U in multiple frequency bands from the client devices **26** in their respective coverage areas **10**(**1**)-**10**(N). The uplink communications signals **20**U received in multiple frequency bands can be routed to different uplink path circuits (not shown) in the remote antenna units **14**(**1**)-**14**(N) related to their frequency band. At the related uplink path circuits in the remote antenna units **14**(**1**)-**14**(N), the uplink communications signals **20**U can be filtered, amplified, and combined together into the combined uplink communications signals **20**U to be distributed to the central unit **16**. The central unit **16** can separate out the received combined uplink communications signals **20**U into their respective bands to distribute to the base station **18**.

Interference of downlink communications signals **20**D and/or uplink communications signals **20**U may occur in the DAS **12** due to non-linear signal processing components provided therein. For example, in the broadband DAS **12** in FIG. **1**, signals in a frequency band of a given downlink communications signal **20**D received and processed by a non-linear signal processing component in the central unit **16** may be duplicated as harmonics in other frequency bands falling within frequency bands of other received downlink communications signals **20**D. For example, an 1800 MHz harmonic may be generated from a 900 MHz downlink communications signal **20**D. Thus, when the downlink communications signals **20**D in their respective frequency bands are combined in the central unit **16** to be distributed to the remote antenna units **14**(**1**)-**14**(N), any harmonics generated from downlink communications signals **20**D may interfere with other downlink communications signals **20**D when combined. Similarly, when received uplink communications signals **20**U are combined in a remote antenna unit **14**(**1**)-**14**(N) to be distributed to the central unit **16**, any harmonics generated from received uplink communications signals **20**U may interfere with other uplink communications signals **20**U when combined. Limiting input power to signal processing components is one method of limiting or avoiding harmonics caused by non-linearity. However, limiting input power can limit dynamic range of the DAS **12** in an undesired manner.

No admission is made that any reference cited herein constitutes prior art. Applicant expressly reserves the right to challenge the accuracy and pertinency of any cited documents.

SUMMARY

Embodiments disclosed herein include frequency shifting a communications signal(s) in a multiple frequency (multi-frequency) distributed antenna system (DAS) to avoid or reduce frequency interference. Related devices, methods, and DASs are also disclosed. Non-limiting examples of frequency interference include frequency band interference and frequency channel interference. For example, frequency interference in a multi-frequency DAS may result from non-lin-

earity of a signal processing component generating an out-of-band harmonic of a first, in-use communications signal in a first frequency band, within different frequency band(s) of other in-use communications signal(s). Thus, to avoid or reduce such interference, certain embodiments involve predicting frequency interference that may result in an in-use communications signal(s) (the "predicted interfered communications signal(s)") as a result of an interfering signal product(s) produced from processing another in-use communications signal in another frequency (the "interference producing communications signal"). If frequency interference is predicted to occur, the frequency of the interference producing communications signal can be shifted in frequency, to in turn shift the frequency of the interfering signal product(s) to appear outside of the frequency of the predicted interfered communications signal(s). Alternatively, or in addition, the frequency of the predicted interfered communications signal(s) can be shifted so that the new, shifted frequency of the predicted interfered communications signal(s) is outside of the frequency of interfering signal product(s). In this manner, as a non-limiting example, frequency interference from any interfering signal products produced as a result of processing in-use communications signals is reduced or avoided, which may allow for higher signal-to-noise ratios (SNR) without having to limit input power. Further, as another example, frequency interference from interference producing communications signals received by antennas in the DAS can also be reduced or avoided.

One embodiment of the disclosure relates to a frequency interference prediction system in a multiple frequency (multi-frequency) distributed antenna system (DAS). The frequency interference prediction system comprises a communications signal interface, comprising a first communications signal interface configured to receive at least one first communications signal in at least one first frequency range, and a second communications signal interface configured to receive at least one second communications signal in at least one second frequency range different from the at least one first frequency range. The frequency interference prediction system also comprises a first communications signal path communicatively coupled to the first communications signal interface. The first communications signal path comprises a first frequency shifting circuit configured to frequency shift the at least one first communications signal from a first frequency in the at least one first frequency range to a shifted first communications signal at a shifted first frequency based on a first frequency control signal. The frequency interference prediction system also comprises a second communications signal path communicatively coupled to the second communications signal interface and configured to provide the at least one second communications signal as an output second communications signal to a second communications signal path output. The frequency interference prediction system also comprises a combiner communicatively coupled to a first communications signal path output and the second communications signal path output, the combiner configured to combine an output first communications signal and the output second communications signal into a combined multi-frequency communications signal. The frequency interference prediction system also comprises a controller. The controller is configured to predict frequency interference in the combined multi-frequency communications signal. If frequency interference is predicted in the combined multi-frequency communications signal, the controller is further configured to determine the shifted first frequency to shift the at least one first communications signal in the combined multi-frequency communications signal and set the at least one first frequency control signal to cause the first frequency shifting circuit to frequency shift the at least one first communications signal to the shifted first communications signal at the shifted first frequency.

Another embodiment of the disclosure relates to a method of avoiding or reducing frequency interference in a multi-frequency DAS. The method comprises receiving at least one first communications signal in at least one first frequency range in a first communications signal path comprising a first communications signal path output. The method also comprises receiving at least one second communications signal in at least one second frequency range different from the at least one first frequency range in a second communications signal path comprising a second communications signal path output. The method also comprises predicting frequency interference in a combined multi-frequency communications signal comprising the at least one first communications signal combined with the at least one second communications signal, as a result of an interfering signal product produced as a result of signal processing at least one of the at least one first communications signal and the at least one second communications signal. If frequency interference is predicted in the combined multi-frequency communications signal, the method also comprises determining a shifted first frequency to shift the at least one first communications signal in the combined multi-frequency communications signal, frequency shifting the at least one first communications signal to a shifted first communications signal at the shifted first frequency, and providing the shifted first communications signal as an output first communications signal to the first communications signal path output. The method also comprises combining the first communications signal path output and the second communications signal path output to provide the combined multi-frequency communications signal.

Another embodiment of the disclosure relates to a multi-frequency DAS. The multi-frequency DAS comprises a central unit. The central unit is configured to receive a combined uplink multi-frequency communications signal from a plurality of remote units. The central unit is also configured to receive a first downlink communications signal in at least one first frequency range and a second downlink communications signal in at least one second frequency range different from the at least one first frequency range. The central unit is also configured to distribute the first downlink communications signal as an output first downlink communications signal to a first downlink communications signal path output and the second downlink communications signal as an output second downlink communications signal to a second downlink communications signal path output. The central unit comprises a combiner communicatively coupled to the first downlink communications signal path output and the second downlink communications signal path output, the combiner configured to combine the output first downlink communications signal and the output second downlink communications signal into a combined downlink multi-frequency communications signal.

The multi-frequency DAS also comprises a plurality of remote units. Each remote unit among the plurality of remote units is configured to receive the combined downlink multi-frequency communications signal from the central unit and distribute the combined downlink multi-frequency communications signal from the central unit to at least one client device. Each remote unit among the plurality of remote units is also configured to receive a first uplink communications signal in at least one first frequency range and a second uplink communications signal in at least one second frequency range different from the at least one first frequency range. Each

remote unit among the plurality of remote units is also configured to distribute the first uplink communications signal as an output first uplink communications signal to a first uplink communications signal path output and the second uplink communications signal as an output second uplink communications signal to a second uplink communications signal path output. Each remote unit among the plurality of remote units comprises a combiner communicatively coupled to the first uplink communications signal path output and the second uplink communications signal path output, the combiner configured to combine the output first uplink communications signal and the output second uplink communications signal into the combined uplink multi-frequency communications signal.

The multi-frequency DAS also comprises a frequency interference prediction system. The frequency interference prediction system comprises a first communications signal path. The first communications signal path comprises a first frequency shifting circuit configured to frequency shift at least one first communications signal among the first downlink communications signal and the first uplink communications signal from a first frequency to a shifted first communications signal at a shifted first frequency based on a first frequency control signal. The frequency interference prediction system also comprises a second communications signal path communicatively configured to provide a second communications signal among the second downlink communications signal and the second uplink communications signal as an output second communications signal to a second communications signal path output among the second downlink communications signal path output and the second uplink communications signal path output. The frequency interference prediction system also comprises a controller. The controller is configured to predict frequency interference in a combined multi-frequency communications signal among the combined downlink multi-frequency communications signal and the combined uplink multi-frequency communications signal. If frequency interference is predicted in the combined multi-frequency communications signal, the controller is further configured to determine the shifted first frequency to shift the at least one first communications signal in the combined multi-frequency communications signal and set the first frequency control signal to cause the first frequency shifting circuit to frequency shift the at least one first communications signal to the shifted first communications signal at the shifted first frequency.

Additional features and advantages will be set forth in the detailed description which follows. Both the foregoing general description and the following detailed description are merely exemplary, and are intended to provide an overview or framework to understand the nature and character of the claims. The drawings provide a further understanding and are part of this specification. The drawings illustrate one or more embodiment(s), and together with the description serve to explain the principles and operation of the various embodiments.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic diagram of an exemplary distributed antenna system (DAS) capable of distributing radio frequency (RF) communications services to client devices;

FIG. **2** is a schematic diagram of an exemplary multi-frequency DAS configured to distribute communications signals in multiple frequency bands;

FIG. **3** is a schematic diagram of exemplary signal processing components in the multi-frequency DAS in FIG. **2** configured to process and combine multiple received communications signals in multiple frequencies into a combined multi-frequency communications signal, and convert the combined multi-frequency communications signal into a combined optical multi-frequency communications signal;

FIG. **4**A is a graph illustrating different frequency bands in a combined multi-frequency communications signal in the multi-frequency DAS in FIG. **2** resulting from combining a first received in-use communications signal and a second received in-use communications signal having different frequency bands;

FIG. **4**B is a graph illustrating an out-of-band interfering signal product of the first received in-use communications signal produced as a result of signal processing the first in-use communications signal, appearing in the frequency band of the second received in-use communications signal in a combined multi-frequency communications signal in the multi-frequency DAS in FIG. **2**;

FIG. **5**A is a graph illustrating the frequency band of the first in-use communications signal in FIG. **4**A down frequency shifted to cause the corresponding out-of-band interfering signal product to be shifted in a combined multi-frequency communications signal, to avoid the out-of-base interfering signal product interfering with the frequency of the second in-use communications signal;

FIG. **5**B is a graph illustrating the frequency band of the first in-use communications signal in FIG. **4**A up frequency shifted to cause the corresponding out-of-band interfering signal product to be shifted in a combined multi-frequency communications signal, to avoid the out-of-base interfering signal product interfering with the frequency band of the second in-use communications signal;

FIG. **5**C is a graph illustrating the frequency band of the second in-use communications signal in FIG. **4**A outside the frequency of the interfering signal product, as a result of up frequency shifting the second in-use communications signal, to avoid the interfering signal product interfering with the frequency band of the second in-use communications signal in the combined multi-frequency communications signal;

FIG. **5**D is a graph illustrating the frequency band of the second in-use communications signal in FIG. **4**A outside the frequency of the interfering signal product, as a result of down frequency shifting the second in-use communications signal, to avoid the interfering signal product interfering with the frequency band of the second in-use communications signal in the combined multi-frequency communications signal;

FIG. **6** is a schematic diagram of an exemplary frequency interference prediction system that can be provided in the multi-frequency DAS in FIG. **2**, and is configured to predict frequency interference in combined multi-frequency communications signal resulting from an interfering signal product(s) produced from processing an in-use communications signal(s) provided in the combined multi-frequency communications signal, and perform frequency shifting of an in-use communications signal(s) to avoid or reduce interfering signal product interference;

FIG. **7** is a flowchart illustrating an exemplary overall process that can be performed by the frequency interference prediction system in FIG. **6** to predict frequency interference in a combined multi-frequency communications signal resulting from an interfering signal product(s) produced from processing an in-use communications signal(s) provided in the combined multi-frequency communications signal, and frequency shift an in-use communications signal(s) to avoid or reduce interfering signal product interference;

FIG. **8** is a flowchart illustrating a specific exemplary process of the process in FIG. **7** that can be performed by the

frequency interference prediction system in FIG. **6** to predict frequency interference and frequency shifting of an in-use communications signal(s) to avoid or reduce frequency interference;

FIG. **9** is a partially schematic cut-away diagram of an exemplary building infrastructure in which a multi-frequency DAS configured to predict frequency interference and perform frequency shifting of an in-use communications signal(s) to avoid or reduce frequency interference can be employed; and

FIG. **10** is a schematic diagram of a generalized representation of an exemplary controller that can be included in any central unit, remote units, wireless client devices, and/or any other components of a multi-frequency DAS.

DETAILED DESCRIPTION

Various embodiments will be further clarified by the following examples.

Embodiments disclosed herein include frequency shifting a communications signal(s) in a multiple frequency (multi-frequency) distributed antenna system (DAS) to avoid or reduce frequency interference. Related devices, methods, and DASs are also disclosed. Non-limiting examples of frequency interference include frequency band interference and frequency channel interference. For example, frequency interference in a multi-frequency DAS may result from non-linearity of a signal processing component generating an out-of-band harmonic of a first, in-use communications signal in a first frequency band, within different frequency band(s) of other in-use communications signal(s). Thus, to avoid or reduce such interference, certain embodiments involve predicting frequency interference that may result in an in-use communications signal(s) (the "predicted interfered communications signal(s)") as a result of an interfering signal product(s) produced from processing another in-use communications signal in another frequency (the "interference producing communications signal"). If frequency interference is predicted to occur, the frequency of the interference producing communications signal can be shifted in frequency, to in turn shift the frequency of the interfering signal product(s) to appear outside of the frequency of the predicted interfered communications signal(s). Alternatively, or in addition, the frequency of the predicted interfered communications signal(s) can be shifted so that the new, shifted frequency of the predicted interfered communications signal(s) is outside of the frequency of interfering signal product(s). In this manner, as a non-limiting example, frequency interference from any interfering signal products produced as a result of processing in-use communications signals is reduced or avoided, which may allow for higher signal-to-noise ratios (SNR) without having to limit input power. Further, as another example, frequency interference from interference producing communications signals received by antennas in the DAS can also be reduced or avoided.

Before discussing examples of frequency shifting a communications signal in a multi-frequency DAS to avoid or reduce frequency interference starting at FIG. **5**A, an exemplary DAS that does not involve frequency shifting to avoid or reduce frequency interference is first discussed with regard to FIGS. **2**-**4**B.

In this regard, FIG. **2** is a schematic diagram of an exemplary multi-frequency optical fiber-based DAS **30** (hereinafter "multi-frequency DAS **30**"). In this example, the multi-frequency DAS **30** includes optical fiber for distributing communications services for multiple frequency bands. The multi-frequency DAS **30** in this example is comprised of three (3) main components. One or more radio interfaces provided in the form of radio interface modules (RIMs) **32**(**1**)-**32**(M) are provided in a central unit **34** to receive and process downlink electrical communications signals **36**D(**1**)-**36**D(R) prior to optical conversion into downlink optical communications signals. The downlink electrical communications signals **36**D(**1**)-**36**D(R) may be received from a base station (not shown) as an example. The RIMs **32**(**1**)-**32**(M) provide both downlink and uplink interfaces for signal processing. The notations "**1**-R" and "**1**-M" indicate that any number of the referenced component, **1**-R and **1**-M, respectively, may be provided. The central unit **34** is configured to accept the plurality of RIMs **32**(**1**)-**32**(M) as modular components that can easily be installed and removed or replaced in the central unit **34**. In one embodiment, the central unit **34** is configured to support up to twelve (12) RIMs **32**(**1**)-**32**(**12**). Each RIM **32**(**1**)-**32**(M) can be designed to support a particular type of radio source or range of radio sources (i.e., frequencies) to provide flexibility in configuring the central unit **34** and the multi-frequency DAS **30** to support the desired radio sources. For example, one RIM **32** may be configured to support the Personal Communication Services (PCS) radio band. Another RIM **32** may be configured to support the 700 MHz radio band. In this example, by inclusion of these RIMs **32**, the central unit **34** could be configured to support and distribute communications signals on both PCS and LTE **700** radio bands, as an example. RIMs **32** may be provided in the central unit **34** that support any frequency bands desired, including but not limited to the US Cellular band, Personal Communication Services (PCS) band, Advanced Wireless Services (AWS) band, 700 MHz band, Global System for Mobile communications (GSM) **900**, GSM **1800**, and Universal Mobile Telecommunication System (UMTS). The RIMs **32**(**1**)-**32**(M) may also be provided in the central unit **34** that support any wireless technologies desired, including but not limited to Code Division Multiple Access (CDMA), CDMA200, 1xRTT, Evolution-Data Only (EV-DO), UMTS, High-speed Packet Access (HSPA), GSM, General Packet Radio Services (GPRS), Enhanced Data GSM Environment (EDGE), Time Division Multiple Access (TDMA), Long Term Evolution (LTE), iDEN, and Cellular Digital Packet Data (CDPD).

The RIMs **32**(**1**)-**32**(M) may be provided in the central unit **34** that support any frequencies desired, including but not limited to US FCC and Industry Canada frequencies (824-849 MHz on uplink and 869-894 MHz on downlink), US FCC and Industry Canada frequencies (1850-1915 MHz on uplink and 1930-1995 MHz on downlink), US FCC and Industry Canada frequencies (1710-1755 MHz on uplink and 2110-2155 MHz on downlink), US FCC frequencies (698-716 MHz and 776-787 MHz on uplink and 728-746 MHz on downlink), EU R & TTE frequencies (880-915 MHz on uplink and 925-960 MHz on downlink), EU R & TTE frequencies (1710-1785 MHz on uplink and 1805-1880 MHz on downlink), EU R & TTE frequencies (1920-1980 MHz on uplink and 2110-2170 MHz on downlink), US FCC frequencies (806-824 MHz on uplink and 851-869 MHz on downlink), US FCC frequencies (896-901 MHz on uplink and 929-941 MHz on downlink), US FCC frequencies (793-805 MHz on uplink and 763-775 MHz on downlink), and US FCC frequencies (2495-2690 MHz on uplink and downlink).

With continuing reference to FIG. **2**, the downlink electrical communications signals **36**D(**1**)-**36**D(R) are provided to a plurality of optical interfaces provided in the form of optical interface modules (OIMs) **38**(**1**)-**38**(N) in this embodiment to convert the downlink electrical communications signals **36**D(**1**)-**36**D(R) into downlink optical communications signals **40**D(**1**)-**40**D(R). The notation "**1**-N" indicates that any num-

ber of the referenced component **1**-N may be provided. The OIMs **38** may be configured to provide one or more optical interface components (OICs) that contain optical to electrical (O/E) and electrical to optical (E/O) converters, as will be described in more detail below. The OIMs **38** support the radio bands that can be provided by the RIMs **32**, including the examples previously described above.

The OIMs **38**(**1**)-**38**(N) each include E/O converters to convert the downlink electrical communications signals **36**D (**1**)-**36**D(R) into the downlink optical communications signals **40**D(**1**)-**40**D(R). The downlink optical communications signals **40**D(**1**)-**40**D(R) are communicated over downlink optical fiber communications medium **42**D to a plurality of remote units **44**(**1**)-**44**(S), which may be remote antenna units. The notation "**1**-S" indicates that any number of the referenced component **1**-S may be provided. O/E converters provided in the remote units **44**(**1**)-**44**(S) convert the downlink optical communications signals **40**D(**1**)-**40**D(R) back into the downlink electrical communications signals **36**D(**1**)-**36**D(R), which are provided to antennas **48**(**1**)-**48**(S) in the remote units **44**(**1**)-**44**(S) to client devices (not shown) in the reception range of the antennas **48**(**1**)-**48**(S).

E/O converters are also provided in the remote antenna units **44**(**1**)-**44**(S) to convert uplink electrical communications signals **50**U(**1**)-**50**U(S) received from client devices (not shown) through the antennas **48**(**1**)-**48**(S) into uplink optical communications signals **40**U(**1**)-**40**U(S). The remote units **44**(**1**)-**44**(S) communicate the uplink optical communications signals **40**U(**1**)-**40**U(S) over an uplink optical fiber communications medium **42**U to the OIMs **38**(**1**)-**38**(N) in the central unit **34**. The OIMs **38**(**1**)-**38**(N) include O/E converters that convert the received uplink optical communications signals **40**U(**1**)-**40**U(S) into uplink electrical communications signals **52**U(**1**)-**52**U(S), which are processed by the RIMs **32**(**1**)-**32**(M) and provided as uplink electrical communications signals **52**U(**1**)-**52**U(S). The central unit **34** may provide the uplink electrical communications signals **52**U(**1**)-**52**U(S) to a base station or other communications system.

Note that the downlink optical fiber communications medium **42**D and uplink optical fiber communications medium **42**U connected to each remote antenna unit **44**(**1**)-**44**(S) may be a common optical fiber communications medium, wherein for example, wave division multiplexing (WDM) may be employed to provide the downlink optical communications signals **40**D(**1**)-**40**D(R) and the uplink optical communications signals **40**U(**1**)-**40**U(S) on the same optical fiber communications medium.

Interference of the downlink electrical communications signals **36**D(**1**)-**36**D(R) and/or the uplink electrical communications signals **50**U(**1**)-**50**U(S) may occur in the multi-frequency DAS **30** in FIG. **2** due to non-linear signal processing components provided therein. For example, communications signals in a frequency band of a given downlink electrical communications signal **36**D received and processed by a non-linear signal processing component in the central unit **34** may be duplicated as harmonics in other frequency bands falling within frequency bands of other received downlink electrical communications signals **36**D. For example, FIG. **3** is a schematic diagram of exemplary signal processing components that can be provided in the central unit **34** in the multi-frequency DAS **30** in FIG. **2** to process the received downlink electrical communications signals **36**D(**1**)-**36**D(R). As shown in FIG. **3**, the received downlink electrical communications signals **36**D(**1**)-**36**D(R) are filtered by respective filters **54**D(**1**)-**54**D(R) and attenuated by respective gain control circuits **56**D(**1**)-**56**D(R) under control of a controller **58**D in the central unit **34**. Interference, such as harmonics of the received downlink electrical communications signals **36**D(**1**)-**36**D(R), may be generated as interfering signal products by the gain control circuits **56**D(**1**)-**56**D(R) and/or the laser diode **68**D due to non-linearity issues. Thus, when the resulting downlink electrical communications signals **36**D(**1**)-**36**D(R) are provided to a combiner **60**D that combines the downlink electrical communications signals **36**D(**1**)-**36**D(R) into a combined multi-frequency communications signal to be provided to any remote units **44**(**1**)-**44**(S) (see FIG. **2**), any interfering signal products generated from downlink electrical communications signals **36**D may interfere with other downlink electrical communications signals **36**D when combined. In this example, the combined multi-frequency communications signal is combined downlink electrical multi-frequency communications signal **62**D. Note that any non-linearity signal processing components located downstream of the combiner **60**D may have a greater chance of producing interference in the combined downlink electrical multi-frequency communications signal **62**D, because a greater number of frequencies may be included in the combined downlink electrical multi-frequency communications signal **62**D.

For example, FIG. **4**A illustrates an exemplary first downlink electrical communications signal **36**D(**1**) centered between the lower frequency f_{LB1} of the first frequency band B**1** and the higher frequency f_{HB1} of the first frequency band B**1**. FIG. **4**A also illustrates an exemplary second downlink electrical communications signal **36**D(**2**) centered between the lower frequency f_{LB2} of the second frequency band B**2** and the higher frequency f_{HB2} of the second frequency band B**2**. FIG. **4**B also illustrates the two downlink electrical communications signals **36**D(**1**), **36**D(**2**) in their respective frequency bands B**1**, B**2** after being combined as combined downlink electrical multi-frequency communications signal **62**D. However, the combined downlink electrical multi-frequency communications signal **62**D also includes a second order harmonic frequency band **64** between $2\times f_{LB1}$ and $2\times f_{HB1}$ that may be generated as a signal product in the combined downlink electrical multi-frequency communications signal **62**D as a result of the central unit **34** in FIG. **2** signal processing the first downlink electrical communications signals **36**D(**1**). For example, the second order harmonic frequency band **64** between $2\times f_{LB1}$ and $2\times f_{HB1}$ may be generated at the laser diode **68**D itself. To this end, FIG. **4**B shows the combined downlink electrical multi-frequency communications signal **62**D with the second harmonic interference **64** that might be generated at a gain control circuit(s) **56**D(**1**)-**56**D(R), the laser diode **68**D and/or the photodiode **72**D. Thus, the second order harmonic frequency band **64** will appear in a combined downlink electrical multi-frequency communications signal **70**D as a result of the photodiode **72** converting the combined downlink optical multi-frequency communications signal **66**D to the combined downlink electrical multi-frequency communications signal **70**D in a remote unit **44** (see also, FIG. **2**). Thus, the second harmonic interference **64** may be generated in combined downlink electrical multi-frequency communications signal **62**D, which is in turn provided in the combined downlink electrical multi-frequency communications signal **70**D after being processed by the photodiode **72**D, or only in combined downlink electrical multi-frequency communications signal **70**D due to the non-linearity issues associated with the laser diode **68**D and/or the photodiode **72**D.

Thus, as shown in FIG. **4**B, the second order harmonic frequency band **64** overlaps with and thus interferes with the second frequency band B**2** in the combined downlink electrical multi-frequency communications signal **70**D. In other

words, the second order harmonic frequency band **64** is an interfering signal product **65** with the second downlink electrical communications signal **36**D(**2**) in the combined downlink electrical multi-frequency communications signal **70**D. Thus, when the combined downlink electrical multi-frequency communications signal **70**D is further processed, the second downlink electrical communications signal **36**D(**2**) will include distortions from such interference. Limiting input power of the first downlink electrical communications signal **36**D(**1**) can limit the interference of the second order harmonic frequency band **64** and can reduce the amplitude of the second order harmonic frequency band **64**, and thus the interference with the second downlink electrical communications signal **36**D(**2**). However, limiting input power can reduce the dynamic range of the multi-frequency DAS **30** in an undesired manner.

Further, with continuing reference to FIG. **3**, when the combined downlink electrical multi-frequency communications signal **62**D is converted to a combined downlink optical multi-frequency communications signal **66**D by a laser diode **68**D in an OIM **38** (FIG. **2**), interference may also be generated in combined downlink optical multi-frequency communications signal **66**D due to any non-linearity issues in the laser diode **68**D. The same interference issues from processing the downlink electrical communications signals **36**D(**1**)-**36**D(R) in the central unit **34** can also occur when the downlink optical communications signals **40**D(**1**)-**40**D(R) are processed by a remote unit **44** (FIG. **2**). For example with reference to FIGS. **4**A-**4**B, as discussed above, the second order harmonic frequency band **64** will appear in a combined downlink electrical multi-frequency communications signal **70**D as a result of the photodiode **72** converting the combined downlink optical multi-frequency communications signal **66**D to the combined downlink electrical multi-frequency communications signal **70**D in a remote unit **44** (see also, FIG. **2**). Again, limiting input power of the downlink electrical communications signals **36**D(**1**)-**36**D(R) received by the central unit **34** processed by the signal processing components is one method of limiting or avoiding downlink interference caused by non-linearity.

In this regard, embodiments disclosed herein include frequency shifting a communications signal(s) in a multi-frequency DAS, such as multi-frequency DAS **30** in FIG. **2**, to avoid or reduce frequency interference. Thus, to avoid or reduce such interference, certain embodiments involve predicting frequency interference that may result in an in-use communications signal(s) (the "predicted interfered communications signal(s)") as a result of an interfering signal product(s) produced from processing another in-use communications signal in another frequency (the "interference producing communications signal"). For example, FIGS. **5**A-**5**D illustrate examples of shifting in-use communications signals with regard to the first and second downlink electrical communications signals **36**D(**1**), **36**D(**2**) in FIGS. **4**A and **4**B, to avoid or reduce such interference.

In the example of FIG. **5**A, an in-use communications signal of the first downlink electrical communications signal **36**D(**1**), as the interference producing communications signal, is down frequency shifted to a lower frequency as down-shifted first downlink electrical communications signal **36**D(**1**)-D in down-shifted band B**1**-D between frequencies $f_{LB1\text{-}D}$ and $f_{HB1\text{-}D}$ from its original frequency band f_{LB2} and f_{HB1} shown in FIG. **4**A. Thus, the second order harmonic frequency band **64** in FIG. **4**A generated from the first downlink electrical communications signal **36**D(**1**) is also down frequency shifted as down-shifted second order harmonic frequency band **64**-D between frequencies $2\times f_{LB2\text{-}D}$ and $2\times f_{HB1\text{-}D}$ as shown in FIG. **5**A. This avoids the down-shifted second order harmonic frequency band **64**-D interfering with frequency range of band B**2** of the second downlink electrical communications signal **36**D(**2**) as an interfered communications signal in combined downlink electrical multi-frequency communications signal **62**D(**1**)-D in FIG. **5**A. By frequency range, it is meant a range of frequencies in which the frequency interference is determined to exist. As discussed in more detail below, a frequency range in which frequency interference is predicted and frequency shifting is performed to avoid or reduce such frequency interference, can be a frequency band, a frequency channel, another other frequency range, or even a single frequency.

Similarly in FIG. **5**B, instead of down frequency shifting first downlink electrical communications signal **36**D(**1**) to avoid interference of the second downlink electrical communications signal **36**D(**2**), the first downlink electrical communications signal **36**D(**1**) is up frequency shifted as up-shifted first downlink electrical communications signal **36**D(**1**)-U to a higher frequency in up-shifted band B**1**-U between frequencies $f_{LB2\text{-}U}$ and $f_{HB1\text{-}U}$ from its original frequency band f_{LB2} and f_{HB1} shown in FIG. **4**A. Thus, the second order harmonic frequency band **64** in FIG. **4**A generated from the first downlink electrical communications signal **36**D(**1**) is also up frequency shifted as up-shifted second order harmonic frequency band **64**-U between frequencies $2\times f_{LB2\text{-}U}$ and $2\times f_{HB1\text{-}U}$ as shown in FIG. **5**B. This avoids the up-shifted second order harmonic frequency band **64**-U interfering with the frequency range of band B**2** of the second downlink electrical communications signal **36**D(**2**) as an interfered communications signal in combined downlink electrical multi-frequency communications signal **70**D(**1**)-U in FIG. **5**B.

Also, in the example of FIG. **4**A, the second downlink electrical communications signal **36**D(**2**) could be shifted in lieu of, or in addition to, the first downlink electrical communications signal **36**D(**1**), as the interfered communications signal to avoid interference with the second order harmonic frequency band **64** generated as a result of signal processing the first downlink electrical communications signal **36**D(**1**). In this regard, in the example of FIG. **5**C, an in-use communications signal of the second downlink electrical communications signal **36**D(**2**), as the interfered communications signal, is down frequency shifted to a lower frequency as down-shifted second downlink electrical communications signal **36**D(**2**)-D in down-shifted band B**2**-D between frequencies $f_{LB2\text{-}D}$ and $f_{HB2\text{-}D}$ from its original frequency band f_{LB2} and f_{HB2} shown in FIG. **4**A. Thus, the second order harmonic frequency band **64** generated from processing the first downlink electrical communications signal **36**D(**1**) between frequencies $2\times f_{LB1}$ and $2\times f_{HB1}$ does not overlap with down-shifted band B**2**-D of the down-shifted second downlink electrical communications signal **36**D(**2**)-D, as shown in FIG. **5**C. This avoids the second order harmonic frequency band **64** interfering with the frequency range of down-shifted band B**2**-D of the down-shifted second downlink electrical communications signal **36**D(**2**)-D in combined downlink electrical multi-frequency communications signal **70**D(**2**)-D in FIG. **5**C.

Similarly in FIG. **5**D, instead of down frequency shifting second downlink electrical communications signal **36**D(**2**) to avoid interference with the second order harmonic frequency band **64**, the second downlink electrical communications signal **36**D(**2**) is up frequency shifted as up-shifted second downlink electrical communications signal **36**D(**2**)-U to a higher frequency in up-shifted band B**2**-U between frequencies $f_{LB2\text{-}U}$ and $f_{LB2\text{-}U}$ from its original frequency band f_{LB2} and F_{HB2} shown in FIG. **4**A. Thus, the second order harmonic

frequency band **64** in FIG. **4**A generated from processing the first downlink electrical communications signal **36**D(**1**) does not overlap up-shifted band B**2**-U of the up-shifted second downlink electrical communications signal **36**D(**2**)-U, as shown in FIG. **5**D. This avoids the second order harmonic frequency band **64** interfering with the frequency range up-shifted band B**2**-U of the down-shifted second downlink electrical communications signal **36**D(**2**)-U in combined downlink electrical multi-frequency communications signal **70**D (**2**)-U in FIG. **5**D.

In either case of FIGS. **5**A and **5**B, as will be described in more detail below, the down-shifted first downlink electrical communications signal **36**D(**1**)-D or the up-shifted first downlink electrical communications signal **36**D(**1**)-U can be frequency shifted back to its original frequency before being communicated to its destination (e.g., an antenna of a remote unit in a DAS). Likewise, in either case of FIGS. **5**C and **5**D, as will be described in more detail below, the down-shifted second downlink electrical communications signal **36**D(**2**)-D or the up-shifted second downlink electrical communications signal **36**D(**2**)-U can be frequency shifted back to its original frequency before being communicated to its destination (e.g., antenna **48** of a remote unit **44** in the multi-frequency DAS **30** in FIG. **2**). Further, although FIGS. **5**A-**5**D illustrate examples of frequency shifting the first and second downlink electrical communications signal **36**D(**1**)-**36**D(**2**), the same principles can be used to frequency shift uplink electrical communications signal **50**U(**1**)-**50**U(S) in the multi-frequency DAS **30** in FIG. **2**.

To provide frequency shifting of in-use communications signals in the multi-frequency DAS **30** in FIG. **2** to avoid or reduce interference, a frequency interference prediction system can be provided therein to predict frequency interference in a combined multi-frequency communications signal and perform frequency shifting to avoid or reduce any predicted frequency interference. In this regard, FIG. **6** is a schematic diagram of an exemplary frequency interference prediction system **80** that can be provided in the multi-frequency DAS **30** in FIG. **2**. As will be discussed in more detail below, the frequency interference prediction system **80** is configured to predict frequency interference in a combined multi-frequency communications signal resulting from an interfering signal product(s) produced from processing an in-use communications signal(s) provided in a combined multi-frequency communications signal **70**D. For example, the combined multi-frequency communications signal may be combined downlink electrical multi-frequency communications signal **70**D (see also, FIG. **3**), or a combined uplink electrical multi-frequency communications signal **70**U in a remote unit **44** (FIG. **2**).

Note that the predicted frequency interference may be performed with regard to predicted interference of communications signals (i.e., data) located within particular channels if the channel frequencies in combined downlink electrical multi-frequency communications signal **70**D are known. The predicted frequency interference may also be performed with regard to predicted interference of communications signals (i.e., data) located within particular frequency bands, typically over a greater frequency range than frequency channels. For example, the channel frequencies included within a combined downlink electrical multi-frequency communications signal **70**D may not be known. Because typically, channel frequencies are more limited in bandwidth range than frequency bands in general, it may be more accurate to predict frequency channel interference than frequency band interference. However, as noted earlier, "frequency interference" encompasses at least both "frequency band interference and "frequency channel interference," without limitation.

The frequency interference prediction system **80** in FIG. **6** will now be described with regard to processing two (2) communications signals, which could be downlink electrical communications signals **36**D(**1**), **36**D(**2**) or uplink electrical communications signals **50**U(**1**), **50**U(**2**). However, note that frequency interference prediction system **80** is not limited to processing and providing frequency shifting to avoid interference with regard to only two (2) communications signals. Further, in FIG. **6**, the notation 'D' designates downlink in the central unit **34** and 'U' designates uplink in a remote unit **44** in the multi-frequency DAS **30** in FIG. **2**, as the frequency interference prediction system **80** can be provided in the central unit **34** for a downlink path and a remote unit **44** for an uplink path.

In this regard, as shown in FIG. **6**, the example of the frequency interference prediction system **80** comprises a first communications signal interface **82**(**1**) and a second communications signal interface **82**(**2**). The first communications signal interface **82**(**1**) is configured to receive a first communications signal **84**(**1**) in a first frequency f_1, which in this example is either downlink electrical communications signal **36**D(**1**) or uplink electrical communications signal **50**U(**1**). The second communications signal interface **82**(**2**) is configured to receive a second communications signal **84**(**2**) as either downlink electrical communications signal **36**D(**2**) or uplink electrical communications signal **50**U(**2**), in a second frequency f_2 different from the first frequency f_1. A first communications signal path **86**(**1**) is communicatively coupled to the first communications signal interface **82**(**1**) to provide the received first communications signal **84**(**1**) to optional filter **54**D(**1**), **54**U(**1**) and/or gain control circuit **56**D(**1**), **56**U(**1**) for signal processing. A second communications signal path **86**(**2**) is communicatively coupled to the second communications signal interface **82**(**2**) to provide the received second communications signal **84**(**2**) to optional filter **54**D(**2**), **54**U (**2**) and/or gain control circuit **56**D(**2**), **56**U(**2**) for signal processing. Note that the first communications signal path **86**(**1**) and the second communications signal path **86**(**2**) could also include optional digital-to-analog converters (DACs) to convert the first and second communications signals **84**(**1**), **84**(**2**) from a digital format to an analog format before being filtered by filters **54**D(**1**), **54**D(**2**), if the first and second communications signals **84**(**1**), **84**(**2**) were received by the central unit **34** in digital format (e.g., in common public radio interface (CPRI) protocol) or converted to digital format in the central unit **34** before reaching the first communications signal path **86**(**1**) and the second communications signal path **86**(**2**).

With continuing reference to FIG. **6**, a first frequency shifting circuit **88**(**1**) is provided in the first communications signal path **86**(**1**) to be able to frequency shift (down-shift or up-shift) the first communications signal **84**(**1**) from its first frequency f_1 to a shifted first communications signal **84**(**1**)-S at a shifted first frequency $f_{1\text{-}S}$ based on a first frequency control signal **96**(**1**). The first frequency shifting circuit **88**(**1**) in this example is comprised of a first mixer **90**(**1**) that is configured to mix a first mixing frequency signal **92**(**1**) generated by a first synthesizer **94**(**1**) in response to the first frequency control signal **96**(**1**). A first selector circuit **98**(**1**) is also provided in the first communications signal path **86**(**1**). The first selector circuit **98**(**1**) is configured to selectively provide the first communications signal **84**(**1**) or the shifted first communications signal **84**(**1**)-S as an output first communications signal **84**(**1**)-O to a first communications signal path output **100**(**1**) in response to a first selector control signal **102**(**1**). In this manner, if it is desired to frequency shift the

first communications signal **84**(**1**) to avoid interference of the second communications signal **84**(**2**), the shifted first communications signal **84**(**1**)-S can be selected by the first selector circuit **98**(**1**) through the first selector control signal **102**(**1**) to be provided to the output first communications signal **84**(**1**)-O to be provided to combiner **60**D, **60**U to be provided in the combined electrical multi-frequency communications signal **62**D, **62**U. The combiner **60**D, **60**U is communicatively coupled to the output first communications signal **84**(**1**)-O. However, if it is not desired or needed to frequency shift the first communications signal **84**(**1**) to avoid interference of the second communications signal **84**(**2**), the first communications signal **84**(**1**) can be selected by the first selector circuit **98**(**1**) through the first selector control signal **102**(**1**) to bypass the first frequency shifting circuit **88**(**1**), or otherwise avoid frequency shifting, and be provided to the output first communications signal **84**(**1**)-O to be provided to combiner **60**D, **60**U to be provided in the combined electrical multi-frequency communications signal **62**D, **62**U.

Similarly with continuing reference to FIG. **6**, a second frequency shifting circuit **88**(**2**) is provided in the second communications signal path **86**(**2**) to be able to frequency shift (down-shift or up-shift) the second communications signal **84**(**2**) from the second frequency f_2 to a shifted second communications signal **84**(**2**)-S at a shifted second frequency $f_{2\text{-}S}$ based on a second frequency control signal **96**(**2**). The second frequency shifting circuit **88**(**2**) in this example is comprised of a second mixer **90**(**2**) that is configured to mix a second mixing frequency signal **92**(**2**) generated by a second synthesizer **94**(**2**) in response to the second frequency control signal **96**(**2**). A second selector circuit **98**(**2**) is also provided in the second communications signal path **86**(**2**). The second selector circuit **98**(**2**) is configured to selectively provide the second communications signal **84**(**2**) or the shifted second communications signal **84**(**2**)-S as an output second communications signal **84**(**2**)-O to a second communications signal path output **100**(**2**) in response to a second selector control signal **102**(**2**). In this manner, if it is desired to frequency shift the second communications signal **84**(**2**) to avoid interference of the first communications signal **84**(**1**), the shifted second communications signal **84**(**2**)-S can be selected by the second selector circuit **98**(**2**) through the second selector control signal **102**(**2**) to be provided to the output second communications signal **84**(**2**)-O to be provided to combiner **60**D, **60**U to be provided in the combined electrical multi-frequency communications signal **62**D, **62**U. The combiner **60**D, **60**U is communicatively coupled to the output second communications signal **84**(**2**)-O. However, if it is not desired or needed to frequency shift the second communications signal **84**(**2**) to avoid interference of the first communications signal **84**(**1**), the second communications signal **84**(**2**) can be selected by the second selector circuit **98**(**2**) through the second selector control signal **102**(**2**) to bypass the second frequency shifting circuit **88**(**2**), or otherwise avoid frequency shifting, and be provided to the output second communications signal **84**(**2**)-O to be provided to combiner **60**D, **60**U to be provided in the combined electrical multi-frequency communications signal **62**D, **62**U.

With continuing reference to FIG. **6**, as previously discussed, it may be desired to frequency shift any shifted first communications signal **84**(**1**)-S or shifted second communications signal **84**(**2**)-S back to its original frequency. In this example, a synchronization control signal **104**D, **104**U that is used to synchronize (frequency and/or phase) the first and second frequency control signals **96**(**1**), **96**(**2**), can be combined in the combined electrical multi-frequency communications signal **62**D, **62**U, so that a recipient of the combined electrical multi-frequency communications signal **62**D, **62**U can use the synchronization control signal **104**D, **106**U to synchronize the reference signals used to mix with the first and/or second communications signals **84**(**1**), **84**(**2**) in the combined electrical multi-frequency communications signal **62**D, **62**U to convert the first and/or second communications signals **84**(**1**), **84**(**2**) back to their original frequencies f_1, f_2, respectively, or other frequency, as desired. In this regard, a management transmitter **106**D, **106**U may provide the synchronization control signal **104**D, **104**U to be added to the combined electrical multi-frequency communications signal **62**D, **62**U in adding component **108** in this example, which can then be filtered out of the combined electrical multi-frequency communications signal **62**D, **62**U in this example to be used for synchronization of return frequency conversions.

With continuing reference to FIG. **6**, in this embodiment of the frequency interference prediction system **80**, a controller **58**D, **58**U is provided to control the frequency shifting decisions for the first and second communications signals **84**(**1**), **84**(**2**). In this regard, FIG. **7** is a flowchart of an exemplary process **110** of the controller **58**D, **58**U predicting potential interference in the combined electrical multi-frequency communications signal **70**D, **70**U and performing frequency shifting to avoid or reduce such interference. In this regard, the controller **58**D, **58**U may first obtain relevant system and configuration data of the multi-frequency DAS **30** to be used in predicting interference in the combined electrical multi-frequency communications signal **70**D, **70**U (block **112**). Examples for possible system and configuration data could be in use frequency bands, detected wanted/unwanted uplink received signals, system/components linearity specifications, system input power, gain, output power, dynamic range, and/or sensitivity, etc. Next, the controller **58**D, **58**U predicts frequency interference in the combined electrical multi-frequency communications signal **70**D, **70**U based on an interference analysis performed on the communications signal **84** (block **114**). The frequency interference predicted by the controller **58**D, **58**U could be frequency band interference or frequency channel interference if the channels included in communications signals **84** are known. If frequency interference is predicted in the combined electrical multi-frequency communications signal **62**D, **62**U, the controller **58**D, **58**U determines the frequency shifting to be performed on the communications signal(s) **84** combined in the combined electrical multi-frequency communications signal **70**D, **70**U to avoid or reduce potential interference in the combined electrical multi-frequency communications signal **70**D, **70**U (block **116**). The controller **58**D, **58**U then frequency shifts the determined communications signal(s) **84** to be frequency shifted to avoid or reduce interference in the combined electrical multi-frequency communications signal **70**D, **70**U (block **118**). For example, as discussed above, if the first communications signal **84**(**1**) is to be frequency shifted, this step involves frequency shifting the first communications signal **84**(**1**) in the first frequency shifting circuit **88**(**1**) in FIG. **6** to the shifted first communications signal **84**(**1**)-S and generating the first selector control signal **102**(**1**) to cause the first selector circuit **98**(**1**) to provide the shifted first communications signal **84**(**1**)-S as the output first communications signal **84**(**1**)-O to the first communications signal path output **100**(**1**). The process **110** can be repeated, as shown in FIG. **7**. Also as discussed above with regard to FIGS. **5**A-**5**D, the communications signal **84** that results in an interfering signal product can be frequency shifted to frequency shift the inter-

fering signal product, and/or other communications signal(s) **84** can be frequency shifted to avoid interfering with the interfering signal product.

FIG. **8** is a flowchart illustrating a specific exemplary process **110**(**1**) of the process **110** in FIG. **7** that can be performed by the frequency interference prediction system **80** in FIG. **6** to predict frequency interference and frequency shift an in-use communications signal(s) to avoid or reduce frequency interference. For example, the process **110**(**1**) in FIG. **8** may be employed by the controller **58**D, **58**U in FIG. **6** to predict frequency band interference or frequency channel interference as a result of frequency band interference or frequency channel interference.

In this regard, with reference to FIG. **8**, the exemplary process can be performed for a downlink path or an uplink path, which is discussed below with the designations 'D' for downlink and 'U' for uplink. In this regard, the controller **58**D, **58**U obtains the service frequency bands (or service frequency channels) supported by the RIMs **32**(**1**)-**32**(M) and the system configuration of the multi-frequency DAS **30** (block **120**). The controller **58**D, **58**U then calculates one or more low spurious interfering signal products ($SPUR_L$) generated from signal processing of the communications signals **36**D or **50**U in the multi-frequency DAS **30** (see FIG. **3**) (block **122**). In this example, the low spurious interfering signal products ($SPUR_L$) are generated from signal processing of the first downlink or uplink communications signals **36**D(**1**) or **50**U(**1**) using the example of a first and second downlink or uplink communications signals **36**D(**1**), **36**D(**2**) or **50**U(**1**), **50**U(**2**). For example, the calculated spurious interfering signal products may be harmonics of first downlink or uplink communications signals **36**D(**1**) or **50**U(**1**). In the example of block **122**, the low spurious interfering signal product is calculated as the second order harmonic of the low frequency band or channel (F_{LB1}) of the first downlink or uplink communications signal **36**D(**1**) or **50**U(**1**), but such is not limiting.

With continuing reference to FIG. **8**, the controller **58**D, **58**U then predicts frequency band interference (or frequency channel interference) in the combined downlink or uplink electrical multi-frequency communications signal **62**D, **62**U based on the low spurious interfering signal product ($SPUR_L$) falling between the low and high frequency bands (F_{LB2} and F_{HB2}) (or frequency channels) of the second downlink or uplink communications signal **36**D(**2**), **50**U(**2**) (block **124**). If the low spurious interfering signal product ($SPUR_L$) falls between the low and high frequency bands (F_{LB2} and F_{HB2}) (or low and high frequency channels) of the second downlink or uplink communications signal **36**D(**2**), **50**U(**2**) (block **124**), this is an indication that frequency interference is likely to occur with the second downlink or uplink communications signal **36**D(**2**), **50**U(**2**) in the combined downlink or uplink electrical multi-frequency communications signal **62**D, **62**U. Thus, the controller **58**D, **58**U frequency shifts the frequency band (or frequency channel) of the first downlink or uplink communications signal **36**D(**1**), **50**U(**1**) so that the low spurious interfering signal product ($SPUR_L$) will fall outside low and high frequency bands (F_{LB2} and F_{HB2}) (or low and high frequency channels) of the second downlink or uplink communications signal **36**D(**2**), **50**U(**2**) (block **126**), and the process repeats.

With continuing reference to FIG. **8**, if the low spurious interfering signal product ($SPUR_L$) does not fall between the low and high frequency bands (F_{LB2} and F_{HB2}) (or low and high frequency channels) of the second downlink or uplink communications signal **36**D(**2**), **50**U(**2**) (block **124**), the controller **58**D, **58**U then predicts frequency band interference (or frequency channel interference) in the combined downlink or uplink electrical multi-frequency communications signal **62**D, **62**U based on calculating high spurious interfering signal product ($SPUR_H$) (block **128**). The controller **58**D, **58**U then determines if the calculating high spurious interfering signal product ($SPUR_H$) falls between the low and high frequency bands (F_{LB2} and F_{HB2}) (or frequency channels) of the second downlink or uplink communications signal **36**D(**2**), **50**U(**2**) (block **130**). If so, the controller **58**D, **58**U frequency shifts the frequency band (or frequency channel) of the first downlink or uplink communications signal **36**D(**1**), **50**U(**1**) so that the high spurious interfering signal product ($SPUR_H$) will fall outside low and high frequency bands (F_{LB2} and F_{HB2}) (or low and high frequency channels) of the second downlink or uplink communications signal **36**D(**2**), **50**U(**2**) (block **126**), and the process repeats.

The multi-frequency DAS **30** in FIG. **2** that includes the frequency interference prediction circuit **80** in FIG. **6** performing frequency shifting of a communications signal(s) **84** to avoid or reduce frequency interference is disclosed may be provided in an indoor environment, as illustrated in FIG. **9**. In this regard, FIG. **9** is a partially schematic cut-away diagram of a building infrastructure **140** employing the multi-frequency DAS **30** that includes the frequency interference prediction circuit **80** in FIG. **6** described above. The building infrastructure **140** in this embodiment includes a first (ground) floor **142**(**1**), a second floor **142**(**2**), and a third floor **142**(**3**). The floors **142**(**1**)-**142**(**3**) are serviced by the central unit **34** to provide the antenna coverage areas **146** in the building infrastructure **140**. The central unit **34** is communicatively coupled to the base station **148** to receive downlink communications signals **36**D from the base station **148**. The central unit **34** is communicatively coupled to the remote antenna units **152** to receive the uplink communications signals **50**U from the remote antenna units **152**, as previously discussed above. The downlink and uplink communications signals **36**D, **50**U communicated between the central unit **34** and the remote antenna units **152** are carried over a riser cable **154**. The riser cable **154** may be routed through interconnect units (ICUs) **156**(**1**)-**156**(**3**) dedicated to each floor **142**(**1**)-**142**(**3**) that route the downlink and uplink communications signals **36**D, **50**U to the remote antenna units **152** and also provide power to the remote antenna units **152** via array cables **158**.

FIG. **10** is a schematic diagram representation of additional detail illustrating a computer system **160** that could be employed in the controllers **58**D, **58**U disclosed herein for controlling the frequency shifting of a communications signal(s) in a multi-frequency DAS to avoid or reduce frequency interference. In this regard, the computer system **160** is adapted to execute instructions from an exemplary computer-readable medium to perform these and/or any of the functions or processing described herein.

In this regard, the computer system **160** in FIG. **10** may include a set of instructions that may be executed to predict frequency interference to avoid or reduce interference in a multi-frequency DAS. The computer system **160** may be connected (e.g., networked) to other machines in a LAN, an intranet, an extranet, or the Internet. While only a single device is illustrated, the term "device" shall also be taken to include any collection of devices that individually or jointly execute a set (or multiple sets) of instructions to perform any one or more of the methodologies discussed herein. The computer system **160** may be a circuit or circuits included in an electronic board card, such as, a printed circuit board (PCB), a server, a personal computer, a desktop computer, a laptop computer, a personal digital assistant (PDA), a computing

pad, a mobile device, or any other device, and may represent, for example, a server or a user's computer.

The exemplary computer system **160** in this embodiment includes a processing device or processor **162**, a main memory **164** (e.g., read-only memory (ROM), flash memory, dynamic random access memory (DRAM), such as synchronous DRAM (SDRAM), etc.), and a static memory **166** (e.g., flash memory, static random access memory (SRAM), etc.), which may communicate with each other via a data bus **168**. Alternatively, the processor **162** may be connected to the main memory **164** and/or static memory **166** directly or via some other connectivity means. The processor **162** may be a controller, and the main memory **164** or static memory **166** may be any type of memory.

The processor **162** represents one or more general-purpose processing devices, such as a microprocessor, central processing unit, or the like. More particularly, the processor **162** may be a complex instruction set computing (CISC) microprocessor, a reduced instruction set computing (RISC) microprocessor, a very long instruction word (VLIW) microprocessor, a processor implementing other instruction sets, or other processors implementing a combination of instruction sets. The processor **162** is configured to execute processing logic in instructions for performing the operations and steps discussed herein.

The computer system **160** may further include a network interface device **170**. The computer system **160** also may or may not include an input **172**, configured to receive input and selections to be communicated to the computer system **160** when executing instructions. The computer system **160** also may or may not include an output **174**, including but not limited to a display, a video display unit (e.g., a liquid crystal display (LCD) or a cathode ray tube (CRT)), an alphanumeric input device (e.g., a keyboard), and/or a cursor control device (e.g., a mouse).

The computer system **160** may or may not include a data storage device that includes instructions **178** stored in a computer-readable medium **180**. The instructions **178** may also reside, completely or at least partially, within the main memory **164** and/or within the processor **162** during execution thereof by the computer system **160**, the main memory **164** and the processor **162** also constituting computer-readable medium. The instructions **178** may further be transmitted or received over a network **182** via the network interface device **170**.

While the computer-readable medium **180** is shown in an exemplary embodiment to be a single medium, the term "computer-readable medium" should be taken to include a single medium or multiple media (e.g., a centralized or distributed database, and/or associated caches and servers) that store the one or more sets of instructions. The term "computer-readable medium" shall also be taken to include any medium that is capable of storing, encoding, or carrying a set of instructions for execution by the processing device and that cause the processing device to perform any one or more of the methodologies of the embodiments disclosed herein. The term "computer-readable medium" shall accordingly be taken to include, but not be limited to, solid-state memories, optical medium, and magnetic medium.

The embodiments disclosed herein include various steps. The steps of the embodiments disclosed herein may be formed by hardware components or may be embodied in machine-executable instructions, which may be used to cause a general-purpose or special-purpose processor programmed with the instructions to perform the steps. Alternatively, the steps may be performed by a combination of hardware and software.

The embodiments disclosed herein may be provided as a computer program product, or software, that may include a machine-readable medium (or computer-readable medium) having stored thereon instructions, which may be used to program a computer system (or other electronic devices) to perform a process according to the embodiments disclosed herein. A machine-readable medium includes any mechanism for storing or transmitting information in a form readable by a machine (e.g., a computer). For example, a machine-readable medium includes: a machine-readable storage medium (e.g., ROM, random access memory ("RAM"), a magnetic disk storage medium, an optical storage medium, flash memory devices, etc.); and the like.

Unless specifically stated otherwise and as apparent from the previous discussion, it is appreciated that throughout the description, discussions utilizing terms such as "processing," "computing," "determining," "displaying," or the like, refer to the action and processes of a computer system, or similar electronic computing device, that manipulates and transforms data and memories represented as physical (electronic) quantities within the computer system's registers into other data similarly represented as physical quantities within the computer system memories or registers or other such information storage, transmission, or display devices.

The algorithms and displays presented herein are not inherently related to any particular computer or other apparatus. Various systems may be used with programs in accordance with the teachings herein, or it may prove convenient to construct more specialized apparatuses to perform the required method steps. The required structure for a variety of these systems will appear from the description above. In addition, the embodiments described herein are not described with reference to any particular programming language. It will be appreciated that a variety of programming languages may be used to implement the teachings of the embodiments as described herein.

Those of skill in the art will further appreciate that the various illustrative logical blocks, modules, circuits, and algorithms described in connection with the embodiments disclosed herein may be implemented as electronic hardware, instructions stored in memory or in another computer-readable medium and executed by a processor or other processing device, or combinations of both. The components of the distributed antenna systems described herein may be employed in any circuit, hardware component, integrated circuit (IC), or IC chip, as examples. Memory disclosed herein may be any type and size of memory and may be configured to store any type of information desired. To clearly illustrate this interchangeability, various illustrative components, blocks, modules, circuits, and steps have been described above generally in terms of their functionality. How such functionality is implemented depends on the particular application, design choices, and/or design constraints imposed on the overall system. Skilled artisans may implement the described functionality in varying ways for each particular application, but such implementation decisions should not be interpreted as causing a departure from the scope of the present embodiments.

The various illustrative logical blocks, modules, and circuits described in connection with the embodiments disclosed herein may be implemented or performed with a processor, a Digital Signal Processor (DSP), an Application Specific Integrated Circuit (ASIC), a Field Programmable Gate Array (FPGA), or other programmable logic device, a discrete gate or transistor logic, discrete hardware components, or any combination thereof designed to perform the functions described herein. Furthermore, a controller may be

a processor. A processor may be a microprocessor, but in the alternative, the processor may be any conventional processor, controller, microcontroller, or state machine. A processor may also be implemented as a combination of computing devices (e.g., a combination of a DSP and a microprocessor, a plurality of microprocessors, one or more microprocessors in conjunction with a DSP core, or any other such configuration).

The embodiments disclosed herein may be embodied in hardware and in instructions that are stored in hardware, and may reside, for example, in RAM, flash memory, ROM, Electrically Programmable ROM (EPROM), Electrically Erasable Programmable ROM (EEPROM), registers, a hard disk, a removable disk, a CD-ROM, or any other form of computer-readable medium known in the art. An exemplary storage medium is coupled to the processor such that the processor can read information from, and write information to, the storage medium. In the alternative, the storage medium may be integral to the processor. The processor and the storage medium may reside in an ASIC. The ASIC may reside in a remote station. In the alternative, the processor and the storage medium may reside as discrete components in a remote station, base station, or server.

The operational steps described herein may be performed in numerous different sequences other than the illustrated sequences. Operation described in a single operational step may actually be performed in a number of different steps, and one or more operational steps may be combined. Information and signals may be represented using any of a variety of technologies and techniques. For example, data, instructions, commands, information, signals, bits, symbols, and chips, that may be references throughout the above description, may be represented by voltages, currents, electromagnetic waves, magnetic fields, or particles, optical fields or particles, or any combination thereof. Unless otherwise expressly stated, it is in no way intended that any method set forth herein be construed as requiring that its steps be performed in a specific order.

Various modifications and variations can be made without departing from the spirit or scope of the invention. The invention should be construed to include everything within the scope of the appended claims and their equivalents.

What is claimed is:

1. A frequency interference prediction system in a multiple frequency (multi-frequency) distributed antenna system (DAS), comprising:

a communications signal interface, comprising:

a first communications signal interface configured to receive at least one first communications signal in at least one first frequency range; and

a second communications signal interface configured to receive at least one second communications signal in at least one second frequency range different from the at least one first frequency range;

a first communications signal path communicatively coupled to the first communications signal interface, the first communications signal path comprising:

a first frequency shifting circuit configured to frequency shift the at least one first communications signal from a first frequency in the at least one first frequency range to a shifted first communications signal at a shifted first frequency based on a first frequency control signal;

a second communications signal path communicatively coupled to the second communications signal interface and configured to provide the at least one second communications signal as an output second communications signal to a second communications signal path output;

a combiner communicatively coupled to a first communications signal path output and the second communications signal path output, the combiner configured to combine an output first communications signal and the output second communications signal into a combined multi-frequency communications signal; and

a controller configured to:

predict frequency interference in the combined multi-frequency communications signal; and

if frequency interference is predicted in the combined multi-frequency communications signal:

determine the shifted first frequency to shift the at least one first communications signal in the combined multi-frequency communications signal; and

set the first frequency control signal to cause the first frequency shifting circuit to frequency shift the at least one first communications signal to the shifted first communications signal at the shifted first frequency.

2. The frequency interference prediction system of claim **1**, wherein:

the controller is configured to:

predict the frequency interference in the combined multi-frequency communications signal based on a first interfering signal product generated from signal processing of the at least one first communications signal in the multi-frequency DAS, interfering in the at least one second frequency range of the at least one second communications signal; and

if frequency interference from the first interfering signal product is predicted in the combined multi-frequency communications signal, the controller is configured to determine the shifted first frequency to shift the at least one first communications signal in the combined multi-frequency communications signal so that the first interfering signal product does not interfere with the at least one second frequency range of the at least one second communications signal.

3. The frequency interference prediction system of claim **1**, wherein:

the controller is configured to:

predict the frequency interference in the combined multi-frequency communications signal, based on a second interfering signal product generated from signal processing of the at least one second communications signal in the multi-frequency DAS interfering in the at least one first frequency range of the at least one first communications signal; and

if frequency interference from the second interfering signal product is predicted in the combined multi-frequency communications signal, the controller is configured to determine the shifted first frequency to shift the at least one first communications signal in the combined multi-frequency communications signal so that the second interfering signal product does not interfere with the at least one first frequency range of the at least one first communications signal.

4. The frequency interference prediction system of claim **2**, wherein the second communications signal path comprises a second frequency shifting circuit configured to frequency shift the at least one second communications signal from a second frequency to a shifted second communications signal at a shifted second frequency based on a second frequency control signal.

5. The frequency interference prediction system of claim 2, further comprising a first selector circuit configured to selectively provide the at least one first communications signal or the shifted first communications signal as the output first communications signal to the first communications signal path output, in response to a first selector control signal;

the controller further configured to, if frequency interference is predicted in the combined multi-frequency communications signal, generate the first selector control signal to cause the first selector circuit to provide the shifted first communications signal as the output first communications signal to the first communications signal path output.

6. The frequency interference prediction system of claim 5, further comprising a second selector circuit configured to selectively provide the at least one second communications signal or a shifted second communications signal as the output second communications signal to the second communications signal path output, in response to a second selector control signal.

7. The frequency interference prediction system of claim 6, wherein:

if frequency interference from a first interfering signal product generated from signal processing of the at least one first communications signal in the multi-frequency DAS is predicted in the combined multi-frequency communications signal, the controller is further configured to generate the second selector control signal to cause the second selector circuit to provide the at least one second communications signal as the output second communications signal to the second communications signal path output.

8. The frequency interference prediction system of claim 4, wherein the controller is further configured to:

predict frequency interference in the combined multi-frequency communications signal based on a second interfering signal product generated from signal processing of the at least one second communications signal in the multi-frequency DAS, interfering in the at least one first frequency range of the at least one first communications signal;

if frequency interference from the second interfering signal product is predicted in the combined multi-frequency communications signal:

determine the shifted second frequency to shift the at least one second communications signal based on the predicted frequency interference in the combined multi-frequency communications signal so that the second interfering signal product does not interfere with the at least one first frequency range of the at least one first communications signal.

9. The frequency interference prediction system of claim 2, wherein:

the at least one first communications signal is in a first frequency band;

the at least one second communications signal is in a second frequency band;

the first frequency shifting circuit is configured to frequency shift the at least one first communications signal from the first frequency band to the shifted first communications signal at a shifted first frequency band based on the first frequency control signal; and

the controller is configured to:

predict frequency band interference in the combined multi-frequency communications signal, based on the first interfering signal product generated from signal processing of the at least one first communications signal in the multi-frequency DAS interfering in the second frequency band of the at least one second communications signal;

if the frequency band interference from the first interfering signal product is predicted in the combined multi-frequency communications signal, set the first frequency control signal to cause the first frequency shifting circuit to frequency shift the at least one first communications signal to the shifted first communications signal at the shifted first frequency outside of the second frequency band of the at least one second communications signal.

10. The frequency interference prediction system of claim 9, wherein the controller is configured to:

predict the frequency band interference in the combined multi-frequency communications signal by being configured to:

calculate at least one first spurious interfering signal product generated from signal processing of the at least one first communications signal in the multi-frequency DAS; and

determine if a frequency of the at least one first spurious interfering signal product is contained in the second frequency band of the at least one second communications signal; and

if the frequency of the at least one first spurious interfering signal product is contained in the second frequency band of the at least one second communications signal, the controller is configured to set the first frequency control signal to cause the first frequency shifting circuit to frequency shift the at least one first communications signal to the shifted first communications signal at the shifted first frequency outside of the second frequency band of the at least one second communications signal.

11. The frequency interference prediction system of claim 3, wherein:

the at least one first communications signal is in a first frequency band;

the at least one second communications signal is in a second frequency band;

the first frequency shifting circuit is configured to frequency shift the at least one first communications signal from the first frequency band to the shifted first communications signal at a shifted first frequency band based on the first frequency control signal; and

the controller is configured to:

predict frequency band interference in the combined multi-frequency communications signal based on the second interfering signal product generated from signal processing of the at least one second communications signal in the multi-frequency DAS, interfering in the first frequency band of the at least one first communications signal;

if the frequency band interference from the second interfering signal product is predicted in the combined multi-frequency communications signal, set the first frequency control signal to cause the first frequency shifting circuit to frequency shift the at least one first communications signal to the shifted first communications signal at the shifted first frequency outside of a frequency of the second interfering signal product and outside of the second frequency band of the at least one second communications signal.

12. The frequency interference prediction system of claim 11, wherein the controller is configured to:

predict the frequency band interference in the combined multi-frequency communications signal by being configured to:

calculate at least one second spurious interfering signal product generated from signal processing of the at least one second communications signal in the multi-frequency DAS; and

determine if a frequency of the at least one second spurious interfering signal product is contained in the first frequency band of the at least one first communications signal; and

if the frequency of the at least one second spurious interfering signal product is contained in the first frequency band of the at least one first communications signal, the controller is configured to set the first frequency control signal to cause the first frequency shifting circuit to frequency shift the at least one first communications signal to the shifted first communications signal at the shifted first frequency outside of the frequency of the second interfering signal product and outside of the second frequency band of the at least one second communications signal.

13. The frequency interference prediction system of claim 2, wherein:

the at least one first communications signal is in at least one first frequency channel;

the at least one second communications signal is in at least one second frequency channel;

the first frequency shifting circuit is configured to frequency shift the at least one first communications signal from the at least one first frequency channel to the shifted first communications signal at a shifted first frequency channel based on the first frequency control signal; and

the controller is configured to:

predict frequency channel interference in the combined multi-frequency communications signal based on the first interfering signal product generated from signal processing of the at least one first communications signal in the multi-frequency DAS, interfering in the at least one second frequency channel of the at least one second communications signal;

if the frequency channel interference from the first interfering signal product is predicted in the combined multi-frequency communications signal, set the first frequency control signal to cause the first frequency shifting circuit to frequency shift the at least one first communications signal to the shifted first communications signal at the shifted first frequency channel outside of the at least one second frequency channel of the at least one second communications signal.

14. The frequency interference prediction system of claim 3, wherein:

the at least one first communications signal is in at least one first frequency channel;

the at least one second communications signal is in at least one second frequency channel;

the first frequency shifting circuit is configured to frequency shift the at least one first communications signal from the at least one first frequency channel to the shifted first communications signal at a shifted first frequency channel based on the first frequency control signal; and

the controller is configured to:

predict frequency channel interference in the combined multi-frequency communications signal based on the second interfering signal product generated from signal processing of the at least one second communications signal in the multi-frequency DAS, interfering in the at least one first frequency channel of the at least one first communications signal;

if the frequency channel interference from the second interfering signal product is predicted in the combined multi-frequency communications signal, set the first frequency control signal to cause the first frequency shifting circuit to frequency shift the at least one first communications signal to the shifted first communications signal at the shifted first frequency channel outside of a frequency of the second interfering signal product and outside of the at least one second frequency channel.

15. The frequency interference prediction system of claim 1, wherein the controller is further configured to provide a synchronization control signal based on the first frequency control signal in the combined multi-frequency communications signal.

16. The frequency interference prediction system of claim 1, further comprising an electrical-to-optical converter configured to convert the combined multi-frequency communications signal into an optical combined multi-frequency communications signal.

17. The frequency interference prediction system of claim 1, wherein the first frequency shifting circuit comprises:

a first synthesizer configured to receive the first frequency control signal and generate a first mixing frequency signal based on the received first frequency control signal; and

a first mixer configured to receive the first mixing frequency signal and the at least one first communications signal, and mix the first mixing frequency signal with the at least one first communications signal to generate the shifted first communications signal.

18. A method of avoiding or reducing frequency interference in a multiple frequency (multi-frequency) distributed antenna system (DAS), comprising:

receiving at least one first communications signal in at least one first frequency range in a first communications signal path comprising a first communications signal path output;

receiving at least one second communications signal in at least one second frequency range different from the at least one first frequency range in a second communications signal path comprising a second communications signal path output;

predicting frequency interference in a combined multi-frequency communications signal comprising the at least one first communications signal combined with the at least one second communications signal, as a result of an interfering signal product produced as a result of signal processing at least one of the at least one first communications signal and the at least one second communications signal;

if frequency interference is predicted in the combined multi-frequency communications signal:

determining a shifted first frequency to shift the at least one first communications signal in the combined multi-frequency communications signal;

frequency shifting the at least one first communications signal to a shifted first communications signal at the shifted first frequency; and

providing the shifted first communications signal as an output first communications signal to the first communications signal path output; and

combining the first communications signal path output and the second communications signal path output to provide the combined multi-frequency communications signal.

19. The method of claim **18**, wherein:

predicting the frequency interference in the combined multi-frequency communications signal comprises predicting the frequency interference in the combined multi-frequency communications signal based on a first interfering signal product generated from signal processing of the at least one first communications signal in the multi-frequency DAS, interfering in the at least one second frequency range of the at least one second communications signal; and

if frequency interference from the first interfering signal product is predicted in the combined multi-frequency communications signal, determining the shifted first frequency by determining the shifted first frequency to shift the at least one first communications signal in the combined multi-frequency communications signal so that the first interfering signal product does not interfere with the at least one second frequency range of the at least one second communications signal.

20. The method of claim **18**, wherein:

predicting the frequency interference in the combined multi-frequency communications signal comprises predicting the frequency interference in the combined multi-frequency communications signal based on a second interfering signal product generated from signal processing of the at least one second communications signal in the multi-frequency DAS interfering in the at least one first frequency range of the at least one first communications signal; and

if frequency interference from the second interfering signal product is predicted in the combined multi-frequency communications signal, determining the shifted first frequency by determining the shifted first frequency to shift the at least one first communications signal in the combined multi-frequency communications signal so that the second interfering signal product does not interfere with the at least one first frequency range of the at least one first communications signal.

21. The method of claim **19**, wherein if frequency interference from the first interfering signal product is predicted in the combined multi-frequency communications signal, not frequency shifting the at least one second communications signal on the second communications signal path output.

22. The method of claim **20**, further comprising:

predicting frequency interference in the combined multi-frequency communications signal based on the second interfering signal product generated from signal processing of the at least one second communications signal in the multi-frequency DAS, interfering in the at least one first frequency range of the at least one first communications signal;

if frequency interference from the second interfering signal product is predicted in the combined multi-frequency communications signal:

determining a shifted second frequency to shift the at least one second communications signal based on the predicted frequency interference in the combined multi-frequency communications signal so that the second interfering signal product does not interfere with the at least one second frequency range of the at least one second communications signal; and

frequency shifting the at least one second communications signal to a shifted second communications signal at the shifted second frequency.

23. The method of claim **19**, wherein:

frequency shifting the at least one first communications signal comprises frequency shifting the at least one first communications signal from a first frequency band of the at least one first communications signal to the shifted first communications signal at a shifted first frequency band based on a first frequency control signal;

predicting the frequency interference comprises predicting frequency band interference in the combined multi-frequency communications signal based on the first interfering signal product generated from signal processing of the at least one first communications signal in the multi-frequency DAS interfering in a second frequency band of the at least one second communications signal; and

if the frequency band interference from the first interfering signal product is predicted in the combined multi-frequency communications signal, frequency shifting the at least one first communications signal to the shifted first communications signal at the shifted first frequency outside of the second frequency band of the at least one second communications signal.

24. The method of claim **23**, wherein:

predicting the frequency band interference in the combined multi-frequency communications signal comprises:

calculating at least one first spurious interfering signal product generated from signal processing of the at least one first communications signal in the multi-frequency DAS; and

determining if a frequency of the at least one first spurious interfering signal product is contained in the second frequency band of the at least one second communications signal; and

if the frequency of the at least one first spurious interfering signal product is contained in the second frequency band of the at least one second communications signal, frequency shifting the at least one first communications signal to the shifted first communications signal at the shifted first frequency outside of the second frequency band of the at least one second communications signal.

25. The method of claim **20**, wherein:

frequency shifting the at least one first communications signal comprises frequency shifting the at least one first communications signal from a first frequency band of the at least one first communications signal to the shifted first communications signal at a shifted first frequency band based on a first frequency control signal;

predicting the frequency interference comprises predicting frequency band interference in the combined multi-frequency communications signal based on the second interfering signal product generated from signal processing of the at least one second communications signal in the multi-frequency DAS, interfering in the first frequency band of the at least one first communications signal; and

if the frequency band interference from a first interfering signal product is predicted in the combined multi-frequency communications signal, frequency shifting the at least one first communications signal to the shifted first communications signal at the shifted first frequency outside of a frequency of the second interfering signal prod-

uct and outside of a second frequency band of the at least one second communications signal.

26. The method of claim **25**, wherein:

predicting the frequency band interference in the combined multi-frequency communications signal comprises:

calculating at least one second spurious interfering signal product generated from signal processing of the at least one second communications signal in the multi-frequency DAS; and

determining if a frequency of the at least one second spurious interfering signal product is contained in the first frequency band of the at least one first communications signal; and

if the frequency of the at least one second spurious interfering signal product is contained in the first frequency band of the at least one first communications signal, frequency shifting the at least one first communications signal to the shifted first communications signal at the shifted first frequency outside of the frequency of the second interfering signal product and outside of the second frequency band of the at least one second communications signal.

27. The method of claim **19**, wherein:

frequency shifting the at least one first communications signal comprises frequency shifting the at least one first communications signal from a first frequency channel to the shifted first communications signal at a shifted first frequency channel based on a first frequency control signal;

predicting the frequency interference comprises predicting frequency channel interference in the combined multi-frequency communications signal based on the first interfering signal product generated from signal processing of the at least one first communications signal in the multi-frequency DAS, interfering in a second frequency channel of the at least one second communications signal; and

if the frequency interference from the first interfering signal product is predicted in the combined multi-frequency communications signal, frequency shifting the at least one first communications signal to the shifted first communications signal at the shifted first frequency outside of the second frequency channel of the at least one second communications signal.

28. The method of claim **20**, wherein:

frequency shifting the at least one first communications signal comprises frequency shifting the at least one first communications signal from a first frequency channel to the shifted first communications signal at a shifted first frequency channel based on a first frequency control signal;

predicting the frequency interference comprises predicting frequency channel interference in the combined multi-frequency communications signal based on the second interfering signal product generated from signal processing of the at least one second communications signal in the multi-frequency DAS, interfering in the first frequency channel of the at least one first communications signal; and

if the frequency interference from the second interfering signal product is predicted in the combined multi-frequency communications signal, frequency shifting the at least one first communications signal to the shifted first communications signal at the shifted first frequency outside of a frequency of the second interfering signal product and outside of a second frequency channel.

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